GWOU ADMINISTRATIVE RECORD
SECTION TITLE:
GW-200-201-1.01

DOE/OR/21548-567

Work Plan for the Remedial Investigation/ Feasibility Study for the Groundwater Operable Units at the Chemical Plant Area and the Ordnance Works Area, Weldon Spring, Missouri

August 1995

U.S. Department of Energy
Weldon Spring Site Remedial Action Project
Weldon Spring, Missouri

DOE/OR/21548-567

Work Plan for the Remedial Investigation/ Feasibility Study for the Groundwater Operable Units at the Chemical Plant Area and the Ordnance Works Area, Weldon Spring, Missouri

August 1995

prepared by

Environmental Assessment Division, Argonne National Laboratory

prepared for

U.S. Department of Energy, Weldon Spring Site Remedial Action Project, Weldon Spring, Missouri, under Contract W-31-109-Eng-38

CONTENTS

CONTENTS (Cont.)

CONTENTS (Cont.)

FIGURES

FIGURES (Cont.)

FIGURES (Cont.)

TABLES

TABLES (Cont.)

NOTATION

The following is a list of the acronyms, initialisms, and abbreviations (including units of measure) used in this document. Acronyms used only in tables are defined in the respective tables.

ACRONYMS, INITIALISMS, AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
ARAR	applicable or relevant and appropriate requirement
Army	U.S. Army
AWQC	ambient water quality criteria
BA	baseline assessment
CE	U.S. Army Corps of Engineers
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLP	Contract Laboratory Program
DNB	dinitrobenzene
DNT	dinitrotoluene
DOE	U.S. Department of Energy
DQO	data quality objective
DQR	data quality requirement
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
FFA	Federal Facility Agreement
FS	feasibility study
GWOU	groundwater operable unit
IT	International Technology (Corporation)
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MW	monitoring well
MWD	deep bedrock well
MWS	shallow bedrock well
MWV	overburden well
NB	nitrobenzene
NCP	National Contingency Plan
NEPA	National Environmental Policy Act
NPL	National Priorities List
PARCC	precision, accuracy, representativeness, completeness, and comparability
PCB	polychlorinated biphenyl
QAPjP	quality assurance project plan
RCRA	Resource Conservation and Recovery Act
RDA	recommended dietary allowance
RfD	reference dose
RI	remedial investigation
ROD	record of decision

SARA	Superfund Amendments and Reauthorization Act
SMCL	secondary maximum contaminant level
SOP	standard operating procedure
TBC	to-be-considered (requirement)
TNB	trinitrobenzene
TNT	trinitrotoluene
USGS	U.S. Geological Survey
WSSRAP	Weldon Spring Site Remedial Action Project

UNITS OF MEASURE

°C	degree(s) Celsius
cm	centimeter(s)
d	day(s)
°F	degree(s) Fahrenheit
ft	foot (feet)
g	gram(s)
ha	hectare(s)
in.	inch(es)
kg	kilogram(s)
km	kilometer(s)
L	liter(s)
m	meter(s)
mg	milligram(s)
mi	mile(s)
mL	milliliter(s)
pCi	picocurie(s)
s	second(s)
t	metric ton(s)
ton	short ton(s)
µg	microgram(s)
µm	micrometer(s)

ENGLISH/METRIC AND METRIC/ENGLISH EQUIVALENTS

In this document, units of measure are presented with the metric equivalent first, followed by the measured English unit in parentheses. In cases where the measurement was originally made in metric units, the values were not converted back to English units; in tables, the data are generally in English or metric units only. The following table lists the appropriate equivalents for English and metric units.

Multiply	By	To Obtain
English/Metric Equivalents		
acres	0.4047	hectares (ha)
cubic feet (ft^3)	0.02832	cubic meters (m^3)
cubic yards (yd^3)	0.7646	cubic meters (m^3)
degrees Fahrenheit (°F) - 32	0.5555	degrees Celsius (°C)
feet (ft)	0.3048	meters (m)
gallons (gal)	3.785	liters (L)
gallons (gal)	0.003785	cubic meters (m^3)
inches (in.)	2.540	centimeters (cm)
miles (mi)	1.609	kilometers (km)
pounds (lb)	0.4536	kilograms (kg)
short tons (tons)	907.2	kilograms (kg)
short tons (tons)	0.9072	metric tons (t)
square feet (ft^2)	0.09290	square meters (m^2)
square yards (yd^2)	0.8361	square meters (m^2)
square miles (mi^2)	2.590	square kilometers (km^2)
yards (yd)	0.9144	meters (m)
Metric/English Equivalents		
centimeters (cm)	0.3937	inches (in.)
cubic meters (m^3)	35.31	cubic feet (ft^3)
cubic meters (m^3)	1.308	cubic yards (yd^3)
cubic meters (m^3)	264.2	gallons (gal)
degrees Celsius (°C) + 17.78	1.8	degrees Fahrenheit (°F)
hectares (ha)	2.471	acres
kilograms (kg)	2.205	pounds (lb)
kilograms (kg)	0.001102	short tons (tons)
kilometers (km)	0.6214	miles (mi)
liters (L)	0.2642	gallons (gal)
meters (m)	3.281	feet (ft)
meters (m)	1.094	yards (yd)
metric tons (t)	1.102	short tons (tons)
square kilometers (km^2)	0.3861	square miles (mi^2)
square meters (m^2)	10.76	square feet (ft^2)
square meters (m^2)	1.196	square yards (yd^2)

WORK PLAN FOR THE REMEDIAL INVESTIGATION/FEASIBILITY STUDY FOR THE GROUNDWATER OPERABLE UNITS AT THE CHEMICAL PLANT AREA AND THE ORDNANCE WORKS AREA, WELDON SPRING, MISSOURI

1 INTRODUCTION

The U.S. Department of Energy (DOE) and the U.S. Army Corps of Engineers (CE) are conducting cleanup activities at two properties, the chemical plant area and the ordnance works area, located adjacent to one another in St. Charles County, Missouri (see Figure 1.1). In accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended, DOE and CE are evaluating conditions and potential responses at the chemical plant area and at the ordnance works area, respectively, to address groundwater and surface water contamination.

The overall strategy for remediation of the chemical plant area provides for groundwater to be addressed as a separate operable unit. Other contaminated media and structures within the chemical plant area have been addressed in a previous operable unit. In a similar manner, the overall remediation strategy for the ordnance works area also provides for groundwater in this area to be addressed as a separate operable unit; soil contamination has likewise been addressed in a previous operable unit. The overall strategies for remediation of the chemical plant area and ordnance works area have been discussed in environmental documentation previously prepared for the two areas (DOE 1992c; U.S. Department of the Army 1993).

Given the current understanding regarding the nature and extent of contamination, as discussed in Chapter 2, addressing groundwater issues through two distinct decision-making processes may be appropriate and advantageous. The first process focuses on impacts resulting from uranium processing, while the second focuses on impacts resulting from operations at the former ordnance works area. Although some overlap exists in this method, groundwater contamination from these operations is largely separable in terms of contaminant type, distribution, and mobility. In addition, the two groundwater operable units (GWOUs) may also differ in terms of remediation potential and applicable technologies. On this basis, pursuing two separate processes may facilitate further investigation, remediation, and decision making. After reviewing this work plan and the results from further sampling as indicated, the agencies involved (i.e., DOE, CE, the U.S. Environmental Protection Agency [EPA], and the Missouri Department of Natural Resources) will determine whether the remainder of the remedial investigation/feasibility study (RI/FS) process will be undertaken jointly or separately by DOE and CE. Until this decision is made, the work plan will assume separate GWOUs to take advantage of the separate operable unit strategy.

This work plan provides a comprehensive evaluation of all areas that are relevant to the GWOUs of both the chemical plant area and the ordnance works area. The evaluation

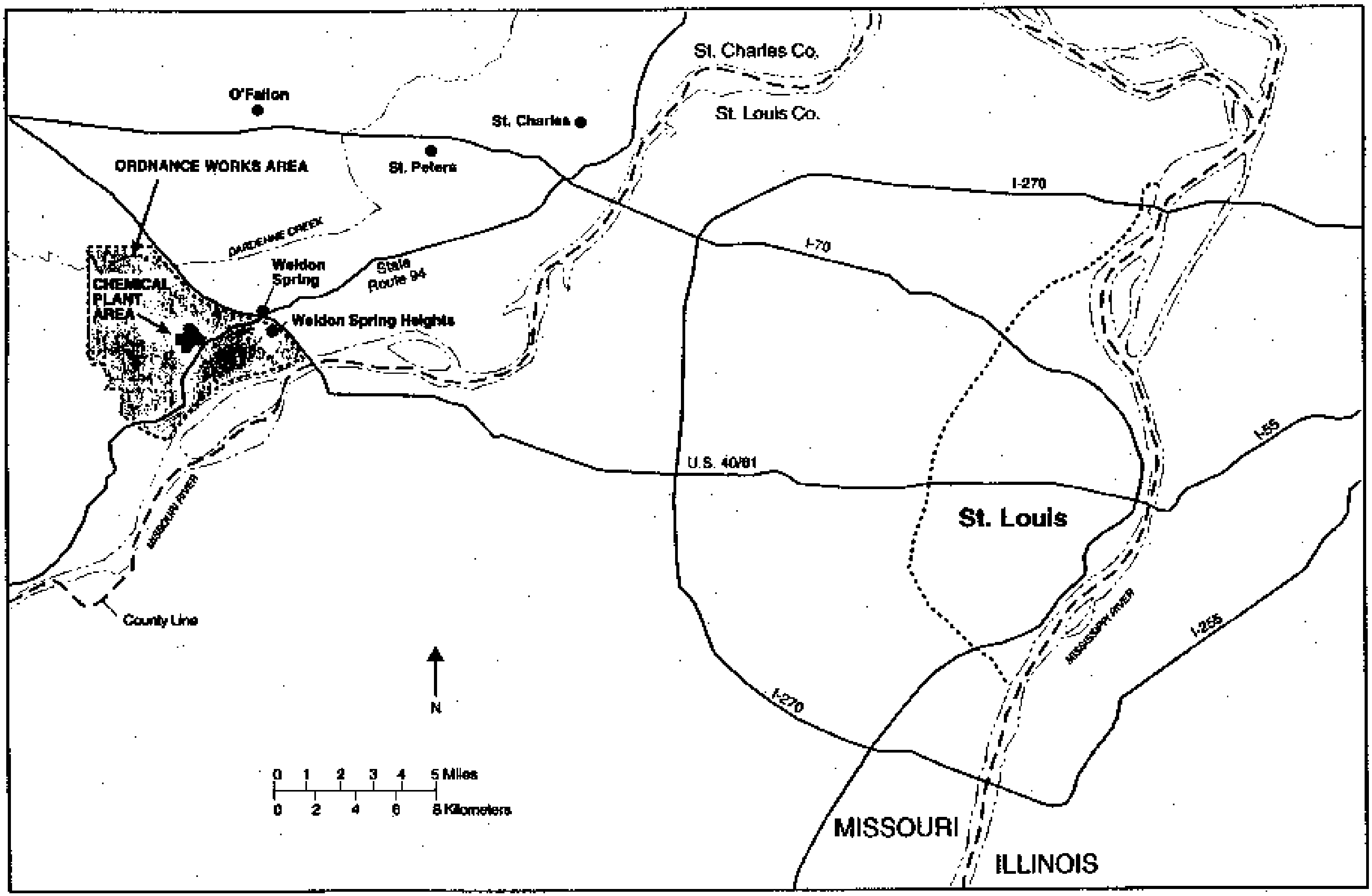


FIGURE 1.1 Location of the Chemical Plant Area and the Ordnance Works Area

presented in this work plan is based on data collected to date by DOE and CE at their respective areas. In some instances, although similar information has been collected by the agencies, dissimilar techniques (e.g., field and laboratory) were employed. Therefore, to further establish and confirm the evaluation presented in this work plan, a joint sampling effort was planned and undertaken by DOE and CE; this sampling, which occurred in May and August 1995, involved all relevant wells and springs in both areas (see Chapter 4 and the Appendix for detailed discussion). Uniform techniques were employed, and DOE was the lead agency in implementing this joint effort. Additional data requirements beyond those data collected via the joint sampling effort are discussed in Section 3.5.

The following areas or media (or both) are addressed in this work plan: (1) groundwater beneath the chemical plant area (including designated vicinity properties described in Section 5 of the RI for the chemical plant area [DOE 1992d]) and beneath the ordnance works area; and (2) surface water and sediment at selected springs, including Burgermeister Spring.

This work plan identifies activities within the RI/FS process as recommended in the EPA guidance for conducting an RI/FS (EPA 1988). The organization of this work plan is as follows:

- Chapter 1 discusses the objectives for conducting the evaluation, including a brief summary of relevant site information and overall environmental compliance activities to be undertaken.

- Chapter 2 presents a brief history of the site and a description of the areas addressed within the GWOUs, along with currently available data.

- Chapter 3 presents a preliminary evaluation of the areas included in the GWOUs, which is based on the information given in Section 2, and discusses data requirements.

- Chapter 4 presents the rationale for data collection or characterization activities to be carried out in the RI phase, along with brief summaries of all supporting documents ancillary to this work plan.

- Chapter 5 discusses the activities planned for the GWOUs under each of the 14 tasks for an RI/FS.

- Chapter 6 presents the proposed schedule for the RI/FS for the GWOUs.

- Chapter 7 briefly explains the project management structure.

1.1 GENERAL SITE INFORMATION

The ordnance works area and the chemical plant area are located in St. Charles County, Missouri, about 48 km (30 mi) west of St. Louis and 22 km (14 mi) southwest of the city of St. Charles (Figure 1.1). The ordnance works area was a former explosives production facility that manufactured trinitrotoluene (TNT) and dinitrotoluene (DNT) for use during World War II. The ordnance works area covers 7,000 ha (17,232 acres), which at the present time includes several contiguous areas with different ownership (see Section 2.1.1). Relatively few of the structures associated with the ordnance works production facility remain.

The 88-ha (217-acre) chemical plant area is located within the boundaries of the ordnance works area. The chemical plant area is chemically and radioactively contaminated as a result of uranium-processing activities conducted by the U.S. Atomic Energy Commission (AEC) during the 1950s and 1960s. Facilities used by the U.S. Army (Army) for the production of explosives in the 1940s were also located in the area now known as the chemical plant.

Both the chemical plant area and the ordnance works area are listed on the EPA's National Priorities List (NPL). Further information about the description and history of these areas is presented in Chapter 2.

1.2 JUSTIFICATION AND OBJECTIVES FOR THE PROPOSED ACTION

The primary threat to human health and the environment associated with the GWOUs is the potential for further release of contaminants. Therefore, remedial actions for the two operable units are being evaluated to eliminate, reduce, or otherwise mitigate the potential for exposure to radioactive and chemical contaminants.

Specific activities that will be conducted to support the determination of appropriate remedial actions for the GWOUs are as follows:

- Confirm contamination in the groundwater beneath the chemical plant area and the ordnance works area;
- Confirm contamination in selected springs, including Burgermeister Spring;
- Evaluate potential impacts to human health and the environment from exposure to contaminants; and
- Evaluate potential remedial action alternatives.

All activities will be conducted in accordance with CERCLA and applicable environmental requirements.

1.3 ENVIRONMENTAL COMPLIANCE PROCESS

Remedial actions at the chemical plant area and the ordnance works area, including the proposed actions at the GWOUs, are conducted according to CERCLA procedures and documentation requirements. The RI/FS conducted under CERCLA is the primary process for environmental compliance associated with remedial actions at the chemical plant area and the ordnance works area.

A recent DOE policy statement regarding the National Environmental Policy Act (NEPA) has set forth a new policy regarding actions taken under CERCLA, such as those taken at the chemical plant area. This new policy states that DOE will rely on the CERCLA process for review of actions taken under CERCLA and will incorporate NEPA values into CERCLA documentation; however, CERCLA work plans such as this one usually will not require the incorporation of NEPA values (DOE 1994a,c).

1.4 EXTERNAL INVOLVEMENT

Activities related to the GWOUs are coordinated with the EPA, state agencies, and the general public. The respective roles of these participants and the coordination of activities are discussed in Sections 1.4.1 through 1.4.3.

1.4.1 Coordination with Other Agencies

The DOE and CE, under Executive Order 12580, have the authority to conduct remedial action at sites under their control. As lead agencies, DOE and CE conduct remedial action activities at the chemical plant area and the ordnance works area in coordination with EPA Region VII and the state of Missouri. Federal Facility Agreements (FFAs), detailing compliance activities of DOE and CE and oversight responsibilities of the EPA and the Missouri Department of Natural Resources, have been negotiated as required by Section 120 of CERCLA. Highlights of these FFAs are summarized in Section 1.4.2.

Plans and activities at the GWOUs are also being coordinated with appropriate state agencies, including the Missouri Department of Natural Resources and the Missouri Department of Conservation. In addition, DOE and CE will continue to coordinate activities for the GWOUs and to exchange information with each other in a timely manner.

1.4.2 Summary of the Federal Facility Agreements

1.4.2.1 Federal Facility Agreement between DOE and EPA

The original FFA was signed by DOE and the EPA in 1986 but has been substantially modified. An amended FFA, which is currently in place for the project, includes stipulations applicable to the GWOU of the chemical plant area. This FFA includes agreements to ensure that the environmental impacts associated with past and present activities at the site area are thoroughly investigated and that appropriate remedial action is taken, as necessary, to protect public health and welfare and the environment. The FFA also establishes a procedural framework and schedule for developing, implementing, and monitoring appropriate response actions at the site in accordance with CERCLA (as amended by the Superfund Amendments and Reauthorization Act [SARA]), the National Contingency Plan (NCP), and applicable or relevant and appropriate laws. This FFA also facilitates the exchange of information among the EPA, DOE, and the state of Missouri and contains procedures for resolving disputes, assigning penalties for nonconformance, and ensuring public participation in the remedial action decision-making process.

As stipulated in the FFA, DOE will prepare and transmit drafts of the primary documents associated with remedial action planning, decision making, and design and construction to the EPA and the Missouri Department of Natural Resources for review and comment. The primary documents associated with the RI/FS for this operable unit that require EPA approval are the work plan, including the sampling plan; the baseline risk assessment; the RI; the FS; the proposed plan; and the record of decision (ROD). Secondary documents that are specified in the FFA for transmittal to the EPA for review and comment include the preliminary analysis of alternatives, any required postscreening investigation work plans or reports, the predecision work plan, treatability studies, and the remedial decision quality assurance project plan (QAPjP).

Appropriate secondary documents identified for the GWOU of the chemical plant area will be stipulated in the FFA progress reports prepared by DOE. These progress reports are submitted quarterly to the EPA, detailing major accomplishments, issues, and milestones. The report describes the status of data collection, environmental documentation, engineering, construction, and procurement. The previous quarter's progress, the current status, and next quarter's planned activities are included for each operable unit.

1.4.2.2 Federal Facility Agreement between the Army and EPA

In 1990, the Army entered into an FFA with the EPA and the Missouri Department of Natural Resources. This FFA includes stipulations applicable to the GWOU of the ordnance works area. The general purposes of this agreement include (1) ensuring that environmental impacts associated with past and present activities at the site area are thoroughly investigated and that appropriate remedial action is taken, as necessary, to protect public health and welfare and the environment; (2) establishing a procedural framework and schedule for developing, implementing, and monitoring appropriate response actions at the site area in accordance with CERCLA/SARA, the NCP, Superfund guidance and policy, the Resource Conservation and Recovery Act (RCRA), RCRA guidance and policy, and applicable laws; and (3) facilitating cooperation, exchange of information, and participation of the parties in such actions.

In accordance with the FFA, the Army will prepare and issue drafts of primary documents for review and comment by the EPA and the Missouri Department of Natural

Resources. Primary documents are defined as those reports that relate to major, discrete portions of RI/FS activities. Primary documents associated with the RI/FS for this operable unit that require EPA approval are the work plan, including the sampling plan; the baseline risk assessment; the RI; the FS; the proposed plan; and the ROD. Secondary documents to be transmitted to the EPA and the Missouri Department of Natural Resources for comment and review may include health and safety plans, initial screening of alternatives, and detailed analysis of alternatives.

1.4.3 Public Participation

The DOE and CE are committed to a program of public participation as part of the remedial action process. A formal community relations program for each site is in place to gather information from the community, inform the public of ongoing and planned activities, and facilitate public input to remedial action decisions. Through these programs, DOE and CE interact with the public by such means as news releases, public meetings, discussions with local interest groups, receipt of and response to public comments, and maintenance of the public repositories for documents and information related to the sites and their cleanup. The community relations plans for the chemical plant area and the ordnance works area are discussed in Chapter 4.

2 SITE BACKGROUND AND SETTING

2.1 SITE DESCRIPTION AND HISTORY

2.1.1 Description

The ordnance works area and the chemical plant area are located in St. Charles County, Missouri, about 48 km (30 mi) west of St. Louis. The Weldon Spring Ordnance Works is a former explosives production facility that manufactured TNT and DNT in the 1940s for use during World War II. The original property encompassed a total area of 7,000 ha (17,232 acres), which has since been divided into several contiguous areas with different ownership. The current disposition of the property is depicted in Figure 2.1. The area includes the chemical plant area and quarry, Weldon Spring Training Area, August A. Busch Memorial Conservation Area, Weldon Spring Conservation Area, Francis Howell High School and Francis Howell Administration Annex, the community of Weldon Spring Heights, University of Missouri Research Park, the county well field, and the maintenance facility of the Missouri Highway Department. The Army currently retains ownership of the 700-ha (1,650-acre) Weldon Spring Training Area, which contained the majority of the production facilities. Public access to the training area is restricted.

The locations of waste disposal operations at the ordnance works area are depicted in Figure 2.2. The facility included 18 TNT and two DNT production lines, four wastewater treatment plants (plant 4 was never operational), and numerous support facilities. Areas used for disposal of wastes and debris include three dumps, one landfill, eight burning grounds, and seven wastewater lagoons. Currently, the ordnance works area has relatively few of the 1,038 structures that comprised the explosives production facility. Most of the buildings were either burned or demolished during initial decontamination activities and subsequent cleanup efforts. Except for a few administrative buildings on the training area, 100 TNT/DNT storage bunkers, the residences in Weldon Spring Heights, and a few storage buildings at Francis Howell High School, only concrete foundations remain of the former ordnance works area. In addition, approximately 25,400 m (83,300 ft) of buried wooden pipeline is believed to remain in the training area.

The 88-ha (217-acre) chemical plant area lies within the boundaries of the ordnance works area. The site was used as a uranium-processing facility from 1957 to 1966. The original layout of the chemical plant area consisted of about 40 buildings, four waste retention ponds referred to as raffinate pits, two ponds (Ash Pond and Frog Pond), and two former dumps (north and south) that are in the process of or planned for remediation (Figure 2.3). The area was contaminated by TNT and DNT production, as well as by subsequent processing of uranium and thorium ores. The area is currently fenced to restrict public access. Burgermeister Spring, included in this operable unit, is located in the August A. Busch Memorial Conservation Area, directly south of Lake 34 (Figure 2.1).

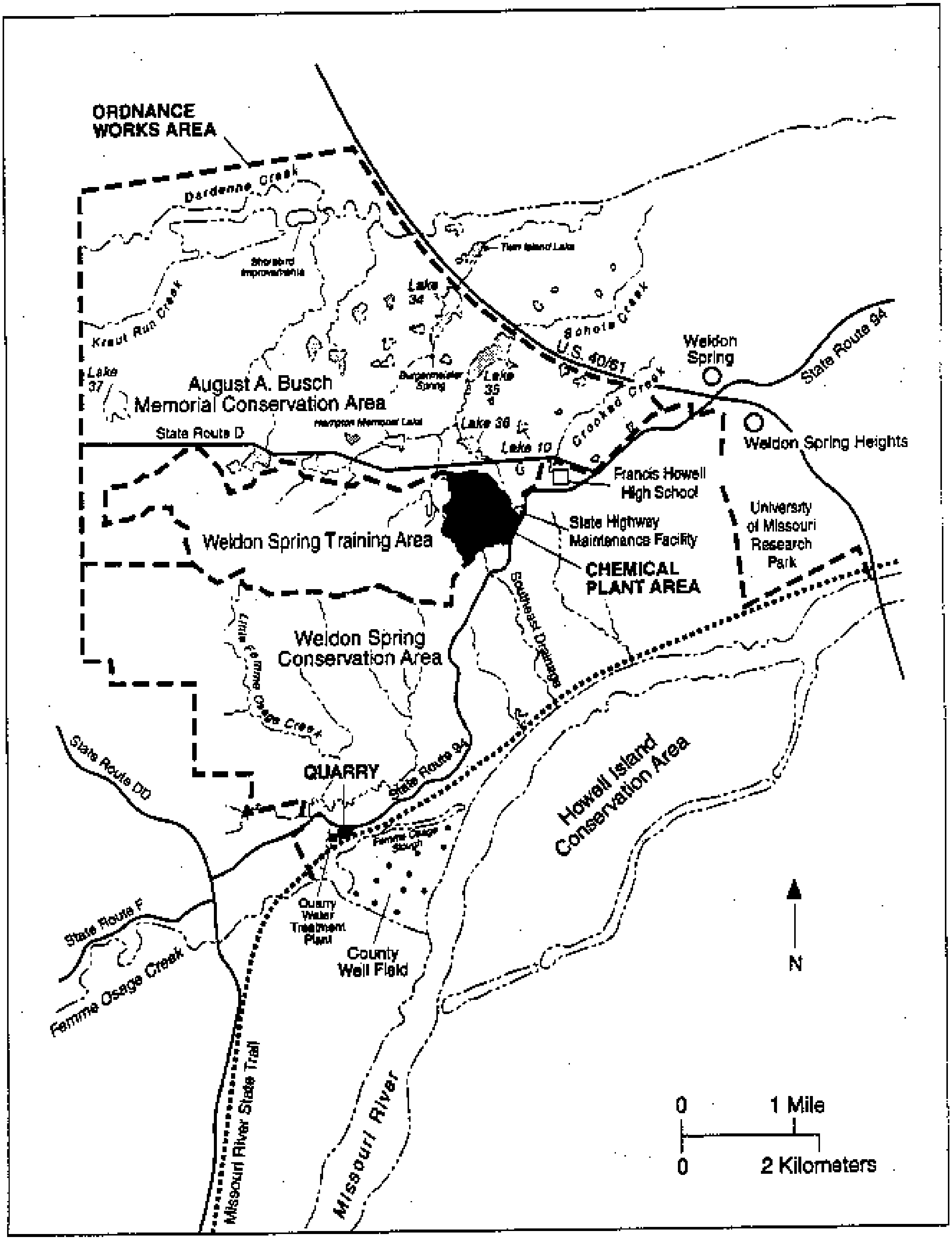


FIGURE 2.1 Current Disposition of the Properties Comprising the Ordnance Works Area

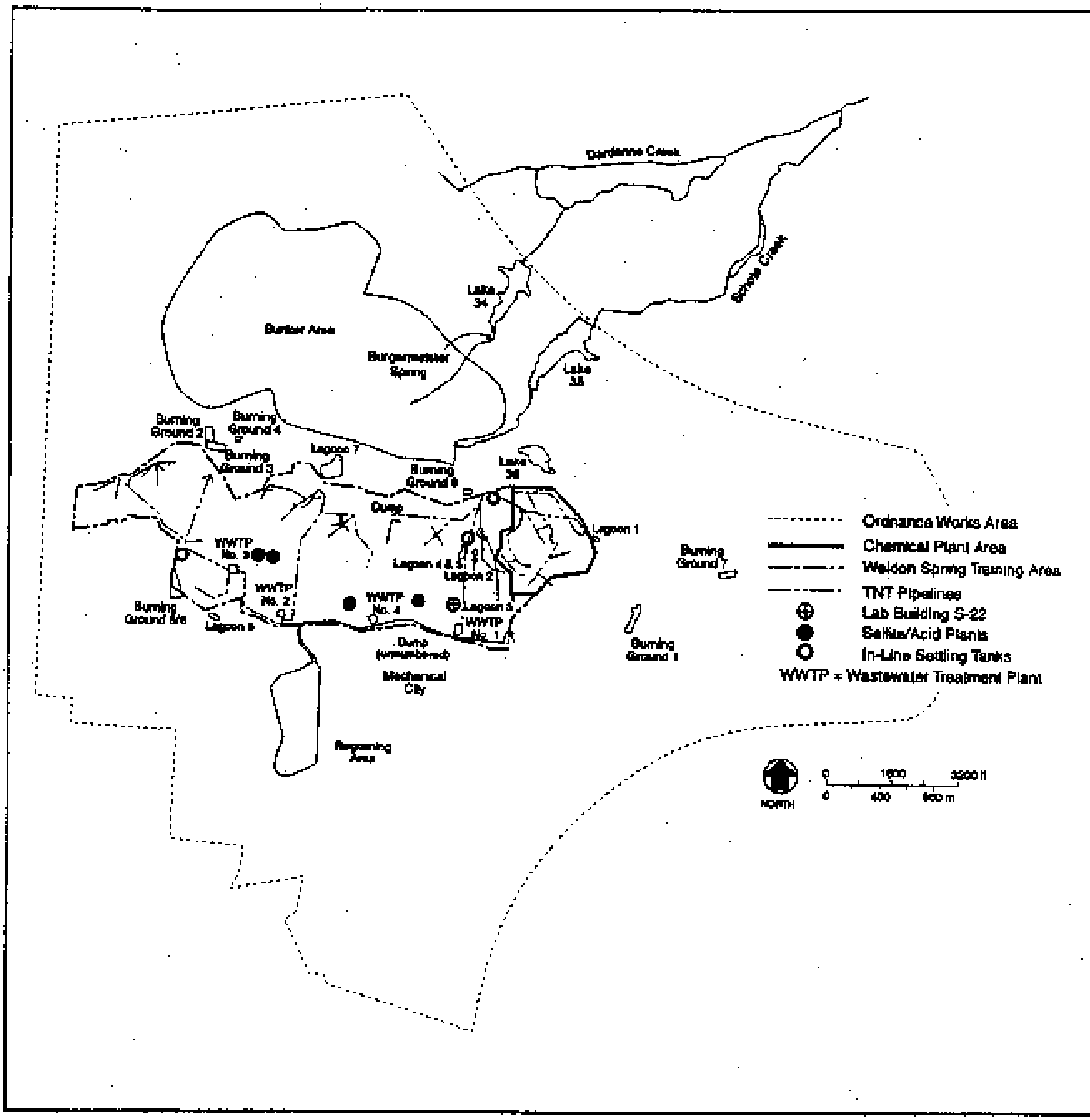


FIGURE 2.2 Locations of Waste Disposal Operations at the Ordnance Works Area

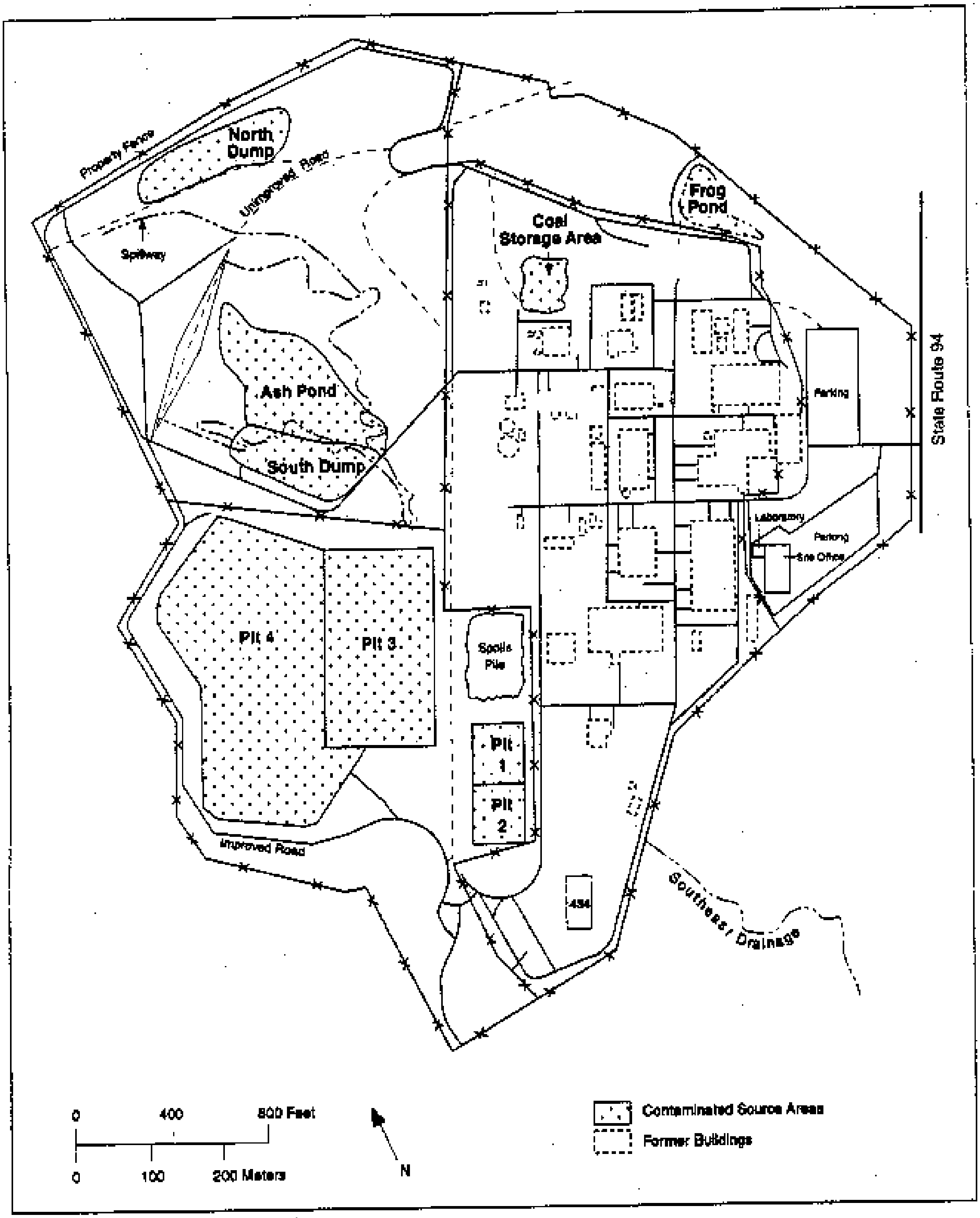


FIGURE 2.3 Original Layout of the Chemical Plant Area

2.1.2 History

The U.S. Department of the Army obtained the land for the Weldon Spring Ordnance Works by direct purchase and condemnation in 1941 from farmers in St. Charles County. Following construction, the Atlas Powder Company operated the facility to produce TNT and DNT explosives from 1941 to 1945. In 1946, the facility was declared surplus property; and by 1949, all but about 810 ha (2,000 acres) of the property (chemical plant area and training area) had been transferred to the state of Missouri and the University of Missouri (International Technology [IT] Corporation 1993f).

The ordnance works area was listed on the NPL in February 1990 (EPA 1990b). The Army is responsible for remediation of this site as stipulated in the FFA among the EPA, the Army, and the Missouri Department of Natural Resources.

In 1955, a total of 83 ha (205 acres) of the ordnance works area was transferred to the AEC (a predecessor of DOE) for construction and operation of the Weldon Spring Uranium Feed Materials Plant, now referred to as the chemical plant; an additional 6 ha (15 acres) was later transferred for expansion of waste storage capacity. The quarry, which had been used by the Army since the early 1940s for disposal of chemically contaminated (explosive) materials, was transferred to the AEC in July 1960 for use as a disposal site for radioactively contaminated materials (Niedermeyer 1976).

The chemical plant was operated for the AEC by the Uranium Division of Mallinckrodt Chemical Works from 1957 to 1966 to process uranium and a limited amount of thorium ore concentrates. Waste slurries were piped to the raffinate pits, where the solids settled to the bottom; the supernatant liquids were decanted to the plant process sewer. This sewer drained off-site to the Missouri River via a 2.4-km (1.5-mi) natural drainage channel referred to as the Southeast Drainage.

In 1985, DOE assumed custody of the chemical plant area and designated the control and decontamination as a Major Project; it was redesignated as a Major System Acquisition in May 1988. In March 1989, the EPA listed the Weldon Spring chemical plant area on the NPL (EPA 1989a).

2.2 PREVIOUS RESPONSE ACTIONS

Cleanup of the ordnance works area is being addressed as discrete components. The first operable unit encompasses cleanup of soils and buried pipeline for which previous documentation has been prepared. This documentation consists of two RI reports (one for the training area and one for the ordnance works area) and an FS, a baseline risk assessment, and a proposed plan (IT Corporation 1992a, 1993a,f-g; U.S. Department of the Army 1993). The proposed action consists of excavation and incineration of wooden pipelines and soils contaminated with nitroaromatic compounds and the permanent disposal of treated residues, contaminated construction debris, and equipment. Soil cleanup standards have been established for the ordnance works area (IT Corporation 1993f).

Removal of the numerous structures that were associated with the ordnance works was previously done as part of five large-scale cleanup actions conducted between 1945 and 1962. These actions focused on the areas now occupied by the training area and the chemical plant area. The various cleanup actions included excavation of soil and removal or burning of structures (IT Corporation 1993f).

Recent removal actions that have been completed at the ordnance works area include removal and storage of interior wallboards contaminated with nitroaromatic compounds from Building S-64 in the former Box Factory Area, removal and detonation of TNT "nuggets" from Burning Ground 1, and fencing of all eight burning grounds.

Cleanup of the chemical plant area consists of several integrated components; previous documentation has been prepared to address components of the project other than the GWOU. A major portion of this documentation was the RI/FS-environmental impact statement (RI/FS-EIS) for the chemical plant area, which was issued in November 1992 and addressed a comprehensive disposal decision for the project (DOE 1992a-d). The RI/FS-EIS proposed appropriate response actions for contaminated media at the chemical plant, including the disposition of contaminated material generated as a result of previous response actions. Soil cleanup standards were established for the site. A decision for on-site treatment and disposal in an engineered disposal cell was made, and a ROD for the decision was signed in September 1993 (DOE 1993a).

In accordance with CERCLA, several expedited response actions were identified prior to a comprehensive decision for the chemical plant area and the ordnance works area to mitigate actual or potential releases of contaminants into the environment. Removal actions at the chemical plant area that have been completed include dismantlement of the chemical plant structures, removal and storage of asbestos from overhead piping, removal of inactive power lines and poles, construction of a dike and diversion system at Ash Pond, removal of polychlorinated biphenyls (PCBs) from electrical equipment, and consolidation and storage of chemicals from various buildings. The removal and the treatment of contaminated surface water in the raffinate pits have also been approved as an interim action and are currently under way.

2.3 ENVIRONMENTAL SETTING

2.3.1 Climate

The ordnance works area and the chemical plant area have a modified continental climate that is characterized by moderately cold winters and warm summers. The region is in the path of cold air moving south from Canada, warm and moist air moving north from the Gulf of Mexico, and dry air from the west. The alternate incursion of these air masses over the site and interactions along the frontal zones result in a wide spectrum of weather conditions, none of which typically persists for a prolonged period of time (Bair 1992).

For the period 1951-1980, the average temperature in the region was 13.0°C (55.4°F); the average daily maximum and minimum temperatures were 31.7°C (89.0°F) in July and -6.7°C (19.9°F) in January, respectively. Temperature extremes over the period 1958-1989 ranged from -28°C (-18°F) to 42°C (107°F). The normal annual precipitation is 86.1 cm (33.9 in.) (Bair 1992). Additional climatic details can be found in the RI reports for the chemical plant area (DOE 1992d) and the ordnance works area (IT Corporation 1992a).

2.3.2 Soils and Geology

The ordnance works area and the chemical plant area lie in the extreme southeastern portion of the Dissected Till Plains, a subdivision of the Central Lowlands Physiographic Province, and are characterized by gently rolling hills in upland areas. The area is just north of the Ozark Plateau Physiographic Province; to the south, the topography changes to narrow ridges and valleys that characterize this province.

Two major soil associations found on the ordnance works area include the Armster-Mexico-Hatton and the Goss-Crider-Gatewood. The Armster-Mexico-Hatton association is found mainly in the northern portion of the ordnance works area (August A. Busch Memorial Conservation Area) and on the training area. The Goss-Crider-Gatewood association is found on the southern portion of the ordnance works area (Weldon Spring Conservation Area) (U.S. Soil Conservation Service 1982; IT Corporation 1992a).

The Harvester-Urban Complex occurs at the southeastern corner of the training area and is the predominant soil type at the chemical plant area (DOE 1992d; IT Corporation 1993a). The Harvester group was transported and shaped by earth-moving equipment at the chemical plant area as a result of past regrading efforts; the Urban group has been covered by roads, parking lots, and other structures (DOE 1992d).

As part of site characterization, a number of investigations have been conducted at the chemical plant area and ordnance works area to describe the local geology (DOE 1992d; Rueff 1992; IT Corporation 1992a, 1993a). Locally, the subsurface consists of unconsolidated deposits that unconformably overlie bedrock. Specific investigations at the training area and the chemical plant area have indicated that the unconsolidated overburden consists mainly of modified loess, glacial drift, a preglacial deposit, and residuum (Rueff 1992; DOE 1992d). The thickness of the overburden deposits generally ranges from 4.6 to 18.3 m (15 to 60 ft) at the chemical plant area (DOE 1992d) and from 3 to 17 m (10 to 55 ft) at the adjacent training area (Rueff 1992; IT Corporation 1993a). The variable thickness of the overburden deposits is controlled by both surface erosion and bedrock topography (DOE 1992d). Additional information on the overburden deposits can be found in the RI reports for the chemical plant area (DOE 1992d) and the ordnance works area (IT Corporation 1992a, 1993a).

Beneath the unconsolidated Quaternary overburden deposits, the subsurface consists primarily of fractured and silicified carbonate units, with some sandstones and shales, from the Mississippian, Devonian, and Ordovician Periods (Table 2.1). The bedrock units exhibit

TABLE 2.1 Generalized Stratigraphy and Hydrostratigraphy in St. Charles County, Including the Chemical Plant Area and the Ordnance Works Area

System	Series	Stratigraphic Unit	Thickness (ft)	Physical Characteristics	Hydrostratigraphic Unit[a]
Quaternary	Holocene	Alluvium	0-120	Gravelly, silty loam	Alluvial aquifer
	Pleistocene	Loess and glacial drift	0-55	Silty clay, silty loam, clay, or loam over residuum from weathered bedrock	(Unsaturated)[b]
Mississippian	Meramecian	Warsaw Formation	0-30	Cherty residuum[c]	(Unsaturated)[b]
	Osagean	Burlington-Keokuk Limestone	0-200	Limestone, coarsely crystalline, thick bedded, cherty	Shallow aquifer system
		Fern Glen Formation	0-70	Limestone, fine-grained, medium to thickly bedded, contains appreciable chert	
	Kinderhookian	Chouteau Group	0-45	Dolomitic limestone; fine-grained, thinly to medium bedded	Upper confining unit
		Bachelor Formation	0-2	Sandstone; calcareous cement	
Devonian	Upper	Sulphur Springs Group			
		Bushberg Sandstone	0-20	Quartz sandstone, fine to medium grained, friable	
		Glen Park Limestone	0-25	Calcareous siltstone, sandstone, uletic limestone, and hard carbonaceous shale	
Ordovician	Cincinnatian	Maquoketa Shale[d]	0-20	Calcareous or dolomitic shale; typically thinly laminated, silty with shaley limestone lenses	
	Champlainian	Kimmswick Limestone	0-150	Limestone, coarsely crystalline, medium to thick bedded, cherty near base	Middle aquifer system
		Decorah Group	0-35	Shale with thin interbeds of very finely crystalline limestone	Lower confining unit

TABLE 2.1 (Cont.)

System	Series	Stratigraphic Unit	Thickness (ft)	Physical Characteristics	Hydrostratigraphic Unit[a]
Ordovician (Cont.)	Champlainian (Cont.)	Plattin Limestone	0-195	Limestone, finely crystalline, thinly bedded	Lower confining unit (cont.)
		Joachim Dolomite	0-135	Dolostone, thin to thickly bedded, grades into siltstone, shales common	
		St. Peter Sandstone	0-250	Quartz sandstone, fine to medium grained, massively bedded	Deep aquifer system
	Canadian	Powell Dolomite	0-65	Dolostone, fine to medium crystalline, minor chert and shale	
		Cotter Dolomite	75-275	Argillaceous, cherty dolomite; fine to medium crystalline; interbedded with shale	
		Jefferson City Dolomite	145-225	Dolomite, fine to medium crystalline	
		Roubidoux Formation	150-170	Dolomitic sandstone	
		Gasconade Dolomite	250[e]	Cherty dolomite and arenaceous dolomite (Gunter Member, about 30 ft thick)	
Cambrian	Upper	Eminence Dolomite	190[e]	Dolomite, medium to coarsely crystalline, medium bedded to massive	
		Potosi Dolomite	100[e]	Dolomite, fine to medium crystalline, thick bedded to massive; drusy quartz common	

[a] When no hydrostratigraphic unit is listed, the unit is the same as for the preceding entry.

[b] These units are saturated in some places at the chemical plant area and the ordnance works area.

[c] The Warsaw Formation present at the chemical plant area and the ordnance works area is found as unconsolidated residuum.

[d] Present in a few places on the ordnance works area and in the eastern part of St. Charles County (Imes 1985).

[e] Range estimates are not available for these units.

Sources: Data from Whitfield et al. (1989); DOE (1992d); Kleeschulte and Imes (1994); and Mugel (1995).

a regional strike of N60W and a regional dip of approximately 1° to the northeast (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1990b). A bedrock high is located in the southwest-central portion of the training area. The bedrock surface slopes gently to the north and more steeply to the south (IT Corporation 1993a). The bedrock surface at the chemical plant area is highest (with respect to mean sea level) in the eastern portion and lowest in the northern to northwestern portion.

The Mississippian units include the Burlington-Keokuk Limestone, Fern Glen Formation, Chouteau Group, and Bachelor Formation (Table 2.1). The Burlington-Keokuk is a fractured, coarsely crystalline, thickly bedded carbonate that contains abundant chert nodules. All monitoring wells on the chemical plant area and most of those on the ordnance works area are completed within the Burlington-Keokuk. The thickness of the Burlington-Keokuk ranges from 0 to <46 m (<150 ft) beneath and in the vicinity of the ordnance works area (IT Corporation 1992a, 1993a) and from 12 to 56 m (40 to 185 ft) at the chemical plant area (Whitfield et al. 1989). Beneath the Burlington-Keokuk is the Fern Glen Formation, a medium to thickly bedded, fine-grained limestone with some layers of chert. The Chouteau Group is a fine-grained limestone beneath the Fern Glen. The Bachelor Formation, beneath the Chouteau, is a sandstone unit.

The Devonian and Ordovician Formations that lie beneath the Mississippian units include the Sulphur Springs Group, Maquoketa Shale, Kimmswick Limestone, Decorah Group, Plattin Limestone, Joachim Dolomite, and St. Peter Sandstone (Table 2.1). The Sulphur Springs Group includes the Bushberg Sandstone and Glen Park Limestone. The Bushberg Sandstone is a fine to medium grained sandstone, and the Glen Park Limestone is an oolitic limestone with some shale. The Maquoketa Shale, beneath the Sulphur Springs Group, ranges from calcareous to dolomitic and, on the basis of well boring data, appears to be discontinuous at the ordnance works area. The Kimmswick Limestone is a coarse, crystalline, medium to thickly bedded limestone that forms the bluffs along the Missouri River bottoms. Beneath the Kimmswick Limestone is the Decorah Group, composed of limestones and shales. Underlying the Decorah Group is the Plattin Limestone, a slightly cherty limestone that is finely crystalline and thinly bedded. The Joachim Dolomite is a fine-grained dolomite with interbedded siltstone and shale units. The St. Peter Sandstone, a fine- to medium-grained quartz sandstone, underlies the Joachim Dolomite (DOE 1992d; IT Corporation 1993a; Mugel 1994a).

The uppermost bedrock unit and the primary focus of these GWOUs is the Burlington-Keokuk Limestone. Subsurface data from 92 vertical and two angled borings collected at the chemical plant area were used to describe the stratigraphic characteristics of the Burlington-Keokuk Limestone (Carman 1991). On the basis of weathering characteristics, the formation has been divided into two units. The upper zone, which is more weathered than the lower portion of the limestone, is referred to as the weathered limestone. The lower zone, which is less weathered, is identified as the unweathered limestone. The stratigraphic boundary between the two units was estimated mainly on the basis of weathering characteristics from borehole data.

Subsurface data obtained from 48 borings at the training area and ordnance works area were also used to describe the stratigraphic characteristics of the Burlington-Keokuk, as well as a few of the deeper formations. Rock cores and boring logs obtained during field operations on the ordnance works area were reviewed, and this upper limestone was divided primarily into two stratigraphic units (i.e., weathered and unweathered), as was done at the chemical plant area. Typically, the unweathered unit is below the weathered unit; however, the borehole data at the ordnance works area indicate that, in some cases, unweathered Burlington-Keokuk Limestone occurs without the weathered limestone unit. At one deep well (deep wells are wells open to units below the Burlington-Keokuk Limestone) at the ordnance works area, the weathered unit of the Burlington-Keokuk directly overlies the Fern Glen Formation (i.e., the unweathered unit is not present) (Mugel 1994a). In conjunction with this work at the ordnance works area, all borehole logs and photographs at the chemical plant area were reviewed to verify the boundary between these two stratigraphic zones. To provide a consistent interpretation of the stratigraphic units within the Burlington-Keokuk at both the chemical plant and ordnance works areas, these tasks were performed in a cooperative effort between CE and DOE. For this effort, the U.S. Geological Survey (USGS) and the Project Management Contractor (Mugel 1994a; Morrison Knudsen Corporation 1994) provided technical support to CE and DOE, respectively.

On the basis of the estimated stratigraphic contact from rock cores and boring logs, the weathered limestone typically ranges in thickness from about 3 to 17 m (10 to 55 ft) at the chemical plant area (DOE 1992d) and from 0 to about 11 m (36 ft) at the ordnance works area; however, at one well location in the ordnance works area, the weathered limestone is 34 m (113 ft) thick (Mugel 1994a). The weathered unit is an argillaceous limestone, commonly containing as much as 60% chert as nodules, breccia fragments, and interbeds. The unit is moderately to highly fractured and slightly to severely weathered, with abundant iron oxide staining and manganese oxide in the rock matrix and along fractures.

At the chemical plant area, core sampling from the angled boreholes indicates that fracturing in the Burlington-Keokuk is predominantly horizontal and typically occurs along shaley interbeds, bedding planes, or chert interbeds. Solution features have also been found, but they are either partially or completely filled with clay-sized material. Although some voids occur in the uppermost bedrock, they are generally isolated and display limited vertical or lateral continuity (Garstang 1991).

In most cases, the unweathered unit underlies the weathered zone of the Burlington-Keokuk Limestone and is thinly to massively bedded and finely to coarsely crystalline and cherty. Both horizontal and vertical fracture densities are significantly lower in the unweathered unit than in the weathered unit (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1990b). On the basis of the subsurface data obtained at the chemical plant area and the ordnance works area, this unit ranges in thickness from 0 to 34 m (0 to 113 ft) (Mugel 1994a). Field data from borehole packer testing of the saturated bedrock also indicate a decrease in hydraulic conductivity with depth (discussed in Section 2.3.3.2), which is attributed to decreased weathering and related solution activity.

2.3.3 Water Resources

2.3.3.1 Surface Water

The ordnance works area and the chemical plant area are located on an east-west drainage divide between the Missouri and Mississippi watersheds (Missouri Department of Natural Resources 1991; IT Corporation 1992a; DOE 1992d). At the western part of the ordnance works area, surface drainage to the south of the divide flows to Little Femme Osage Creek and its tributaries, which ultimately discharge into the Missouri River (surface drainages are shown in Figure 2.4). At the eastern part of the ordnance works area, surface drainage to the south of the divide flows toward and discharges to the Missouri River. Surface drainage to the north of the divide flows toward Dardenne Creek and its tributaries. Schote Creek, the largest of the tributaries, drains a major portion of the training area and the chemical plant area. Dardenne Creek flows easterly and ultimately into the Mississippi River (IT Corporation 1992a; DOE 1992d). Because of the presence of the surface drainage divide, surface water from the chemical plant area flows to the adjacent ordnance works area.

Seepage runs were conducted by the USGS to determine which streams in the area were losing or gaining water. The Missouri Department of Natural Resources evaluated the losing and gaining characteristics of the streams by using repeated field observations, water-tracing data, stream gauging, and the USGS seepage-run data. In the Mississippi River watershed, the studies showed that Dardenne Creek gained water along the reach that passes through the ordnance works area. Kraut Run gained water throughout its length. The two tributaries that form the source of Schote Creek on the training area both gained water until they reached the area just above Hampton Memorial Lake. The stream that flows through Burgermeister Spring valley into Lake 34 gained water throughout its length. The stream originating at Lake 28, which crosses the western edge of the training area, gained water for the first part of its length but became a losing stream before crossing the August A. Busch Memorial Conservation Area (Missouri Department of Natural Resources 1991).

In the Missouri River watershed, Little Femme Osage Creek gained and lost water along its length. Drainage 5500 and its tributaries lost water in their upper reaches near the training area but quickly became gaining. Drainages 5100, 5200, 5300 (Southeast Drainage), and 5400 southeast of State Route 94 tended to be losing streams in their upper reaches near State Route 94 but gained water as they approached the Missouri River floodplain.

Surface water flow was interrupted by the construction of fishing lakes for the August A. Busch Memorial Conservation Area by the Missouri Department of Conservation. Most of these lakes were made by damming the tributaries of Dardenne Creek. A total of 38 lakes and numerous fishing ponds were constructed (Missouri Department of Conservation 1989). In addition to these lakes and ponds, several ponds and a lake exist in the Weldon Spring Conservation Area south of U.S. Route 40/61 and east of State Route 94. The training area contains no natural ponds, although wastewater lagoons and settling basins form many man-made surface water bodies (IT Corporation 1993a).

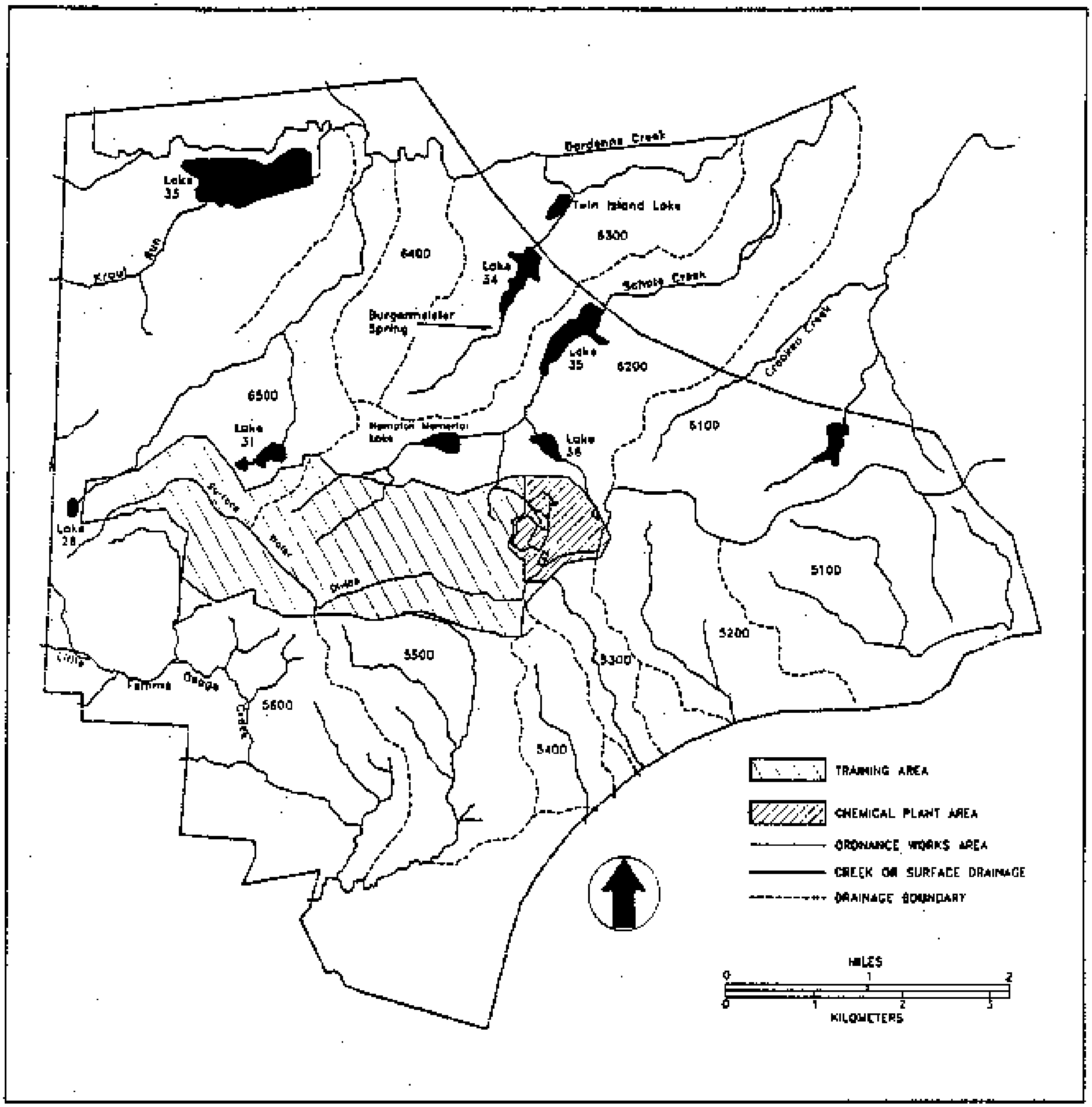


FIGURE 2.4 Locations of Surface Drainages at the Ordnance Works Area and the Chemical Plant Area

During construction of the ordnance works, natural site drainage apparently dictated the construction locations of wastewater lagoons and TNT production plant buildings. An early site investigation noted that small tributary branches extended up to most of the production buildings, from which red water was discharged. In places where gullies or draws were not available, small ditches were excavated from the source of the discharge to the nearest tributary (Fishel and Williams 1944). Lagoons were strategically constructed within these tributaries to intercept and retain the discharged waste. Six lagoons are located within the Mississippi River drainage basin, and one lagoon is within the Missouri River drainage basin. Lagoons 1, 2, 4, and 5 have been backfilled; lagoons 3 and 6 were drained and not backfilled. All of the lagoons except 1 and 2 are either partially or completely filled with water. Lagoon 7 is now Lake 16 (IT Corporation 1993g).

During site reconnaissance, settling tanks for each waste-generating building were noted to be constructed in excavated pits at or near the former discharge streams. Once wastewater pipelines and treatment plants were constructed, direct discharge into northern streams was diverted. Waste was fed by gravity into settling tanks and was subsequently pumped over the drainage divide to waste treatment plants located within the southern portion of the training area. Effluent from the treatment plants was discharged via pipeline into the Southeast Drainage (5300), rather than into the northern streams (IT Corporation 1993a). The Southeast Drainage discharges into the Missouri River.

The major surface water features at the chemical plant area are man-made and were developed in conjunction with historical operations. The four raffinate pits encompass about 10.9 ha (27 acres) and, because of berm construction, no longer contribute to surface runoff. Ash Pond covers about 4.5 ha (11 acres) and is located in a topographic low near the northern boundary of the site; Frog Pond covers about 0.3 ha (0.7 acres) near the eastern boundary of the site.

Included in these operable units is Burgermeister Spring, which is a major spring with perennial flow. This spring is located immediately upstream of Lake 34 in the August A. Busch Memorial Conservation Area (DOE 1992d).

2.3.3.2 Hydrogeology

Regional. The three principal bedrock aquifer systems present in the Weldon Spring region include a shallow unconfined aquifer (although it may be confined in some local areas), a confined middle aquifer, and a deep confined aquifer. These systems are separated by confining units made up of limestone, dolomite, sandstone, and shale formations (Kleeschulte and Imes 1994). Regionally, the shallow bedrock aquifer primarily consists of saturated rocks of the Burlington-Keokuk Limestone and Fern Glen Formation, and the middle aquifer is composed of the Kimmswick Limestone. The deep bedrock aquifer system consists of Ordovician and Upper Cambrian saturated rocks, which include formations from the St. Peter Sandstone down through the Potosi Dolomite (Kleeschulte and Emmett 1987). Groundwater that is used as a drinking water supply in the area is primarily taken from the deep productive aquifer of the Ordovician/Cambrian bedrock system and from an alluvial aquifer near the Missouri River; however, in St. Charles County, the shallow and middle aquifers are also used, mainly for rural domestic water supply (Kleeschulte 1991).

The water quality in the vicinity of the Weldon Spring site has been routinely monitored by the Missouri Department of Health (Clardy 1995). The current monitoring program consists of 37 residential wells located north and west of the Weldon Spring chemical plant and training areas; data are available for 63 wells, but many are no longer monitored for various reasons (e.g., pump failures). Gross alpha and gross beta are routinely analyzed in the residential wells. Data collected indicate that gross alpha ranges from 1 to 65 pCi/L, and gross beta ranges from 1 to 29 pCi/L. Other radiological parameters that are occasionally analyzed include uranium, radium-226, radium-228, thorium-230, and thorium-232. Chemical parameters that are routinely analyzed are nitrate, sulfate, and lithium. Levels of nitrate and sulfate range from 0.05 to 27.5 mg/L and from 8 to 130 mg/L, respectively. Lithium has never been detected in any of the groundwater samples. Other parameters that have been analyzed include chloride, fluoride, lead, and total dissolved solids.

Weldon Spring Area. The groundwater system of primary interest in the Weldon Spring area is the shallow bedrock aquifer, which consists of a series of hydraulically connected limestones and, in some locations, the overlying saturated residuum or glacial drift. The shallow aquifer includes the Burlington-Keokuk Limestone, which is the uppermost bedrock formation beneath the chemical plant area and most of the ordnance works area. The principal recharge to this shallow groundwater system is through infiltration of precipitation from the overburden or from losing streams. The shallow groundwater system is the focus of these operable units because of impacts from previous activities.

Water-level elevations were measured in monitoring wells at the ordnance works area and the chemical plant area by the USGS during the period of 1987 through 1993. A map of the potentiometric surface of the shallow aquifer, constructed from average water-level measurements collected during the period, is shown in Figure 2.5. Most of the data used to contour this map were water levels measured in wells completed partially or totally within the weathered portion of the Burlington-Keokuk Limestone. A hydrogeological data review and relogging of the chemical plant area and ordnance works area rock core were performed recently by the DOE Project Management Contractor and the USGS, working in cooperation with CE. This effort provided a common interpretation of the weathered and unweathered stratigraphic units within the Burlington-Keokuk Limestone and also verified the units monitored by the wells at each site.

The shallow aquifer is primarily unconfined, although it may be confined in a few local areas. The water-table elevation fluctuates seasonally and with precipitation but remains within the upper bedrock, residuum, or glacial drift. On the basis of the water-table

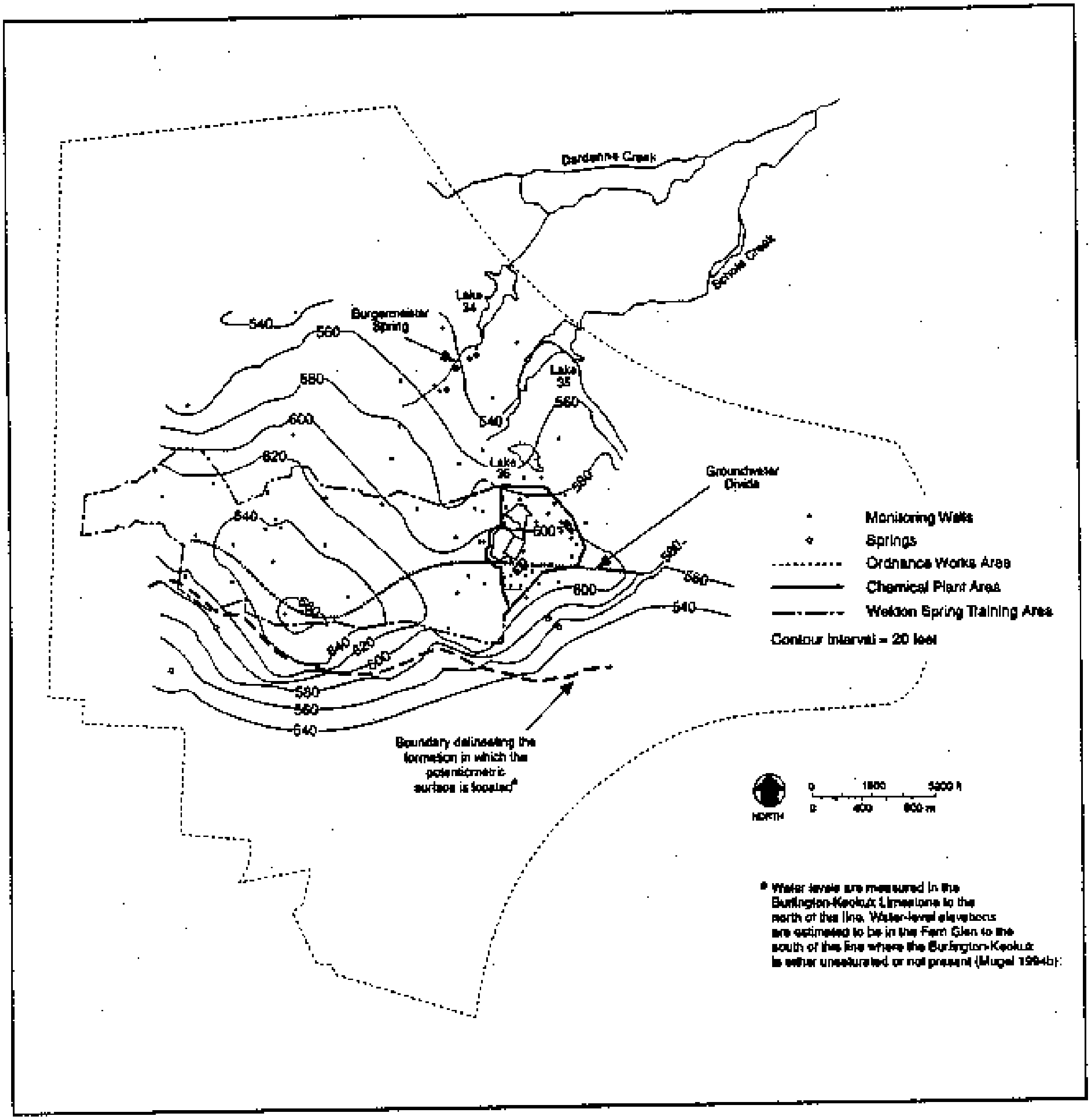


FIGURE 2.5 Contour Map of the Potentiometric Surface of the Shallow Aquifer at the Chemical Plant Area and the Ordnance Works Area

map discussed previously and shown in Figure 2.5, other maps presented in the RI reports for the chemical plant area and the ordnance works area, and information in reports by the USGS and the Missouri Department of Natural Resources, an east-west trending groundwater divide has been identified that results in two distinct drainage systems (Missouri Department of Natural Resources 1991; DOE 1992d; IT Corporation 1992a; Kleeschulte and Imes 1994).

At the ordnance works area, shallow groundwater north of the divide flows to the north, and shallow groundwater south of the divide flows to the south following natural gradients. The eventual discharge points for groundwater flow are tributaries of the Mississippi and Missouri Rivers. In the northeastern portion of the training area and northwest of the chemical plant area, a subsurface conduit transports water rapidly to Burgermeister Spring. The presence of this conduit feature (a subsurface pathway in which water flows at a high velocity and does not obey Darcy's law [White 1988]) is inferred by a groundwater trough in the contoured water-table surface south of Burgermeister Spring (see Figure 2.5). Water-tracing tests (discussed later in this section) provide additional evidence for the presence of a conduit in this area; other conduit features identified by the Missouri Department of Natural Resources appear not to coincide with groundwater troughs (Missouri Department of Natural Resources 1991; Price 1991). These features are located north and south of the training area.

The Burgermeister Spring area appears to be a major groundwater discharge area for drainage from the eastern and central portions of the training area and the northern portion of the chemical plant area. Groundwater in the northwestern portion of the training area flows to two western valleys (i.e., the 6500 drainage and a small drainage to the west of the 6500 drainage [see Figure 2.4]) (IT Corporation 1993a).

Groundwater flow in the southern portion of the ordnance works area stays within its surface drainage. The map of the water-table surface presented in Figure 2.5 and maps in previous RI reports for the ordnance works area and the training area do not show distinct troughs or highs south of the groundwater divide (IT Corporation 1992a, 1993a), although this finding may be a function of the number of data points.

Mapping of the upper aquifer potentiometric surface by the Missouri Department of Natural Resources (1991) suggests the presence of two troughs south of the groundwater divide in the areas of monitoring wells MWS 18 and MWS 5; however, the results of the relogging effort at the ordnance works area indicated that MWS 18 and MWS 5 are open to units deeper than the weathered Burlington-Keokuk (see Section 2.4.5) (Mugel 1994a). The data from these two wells, which created the trough features in the potentiometric surface, were not included in the construction of the map of the potentiometric surface of the shallow aquifer presented in Figure 2.5.

At the chemical plant area, groundwater to the north of the divide flows north and west toward Burgermeister Spring and eventually toward Dardenne Creek, a tributary of the Mississippi River. Groundwater to the south of the divide flows south to southeast toward the Missouri River, primarily through the 5300 drainage (see Figure 2.5). Because the

Southeast Drainage is a losing stream in its upper reaches, mixing between groundwater and surface water runoff can occur. The direction of groundwater flow in the drainage is from the chemical plant area to the adjacent ordnance works area.

Vertical gradients within the shallow groundwater system have been measured in well clusters at both the ordnance works and chemical plant areas. At the ordnance works area, where 10 clustered wells are open to the overburden and open to the Burlington-Keokuk Limestone, downward gradients are observed most of the time, except in one well pair where the predominant gradient is upward. Downward gradients are observed between 12 clustered well pairs open to the weathered unit and open to the unweathered unit of the Burlington-Keokuk at (11 well pairs) and near (one well pair) the chemical plant area. At the ordnance works area, where two well clusters of this type exist, a downward gradient is observed in one well pair and an upward gradient in the other. At the ordnance works area, three wells open to the unweathered Burlington-Keokuk are clustered with wells open partially to the Fern Glen Formation; an upward gradient is observed at these well clusters (IT Corporation 1993a). Additional water-level information regarding these well clusters at the ordnance works area and the chemical plant area can be found in previous RI reports (IT Corporation 1992a, 1993a; DOE 1992d) and in quarterly monitoring reports (IT Corporation 1992b-d, 1993b-e, 1994a-c).

Hydraulic conductivities of the shallow bedrock aquifer (i.e., Burlington-Keokuk Limestone) at the chemical plant area were estimated with three different hydraulic testing methods: packer tests, slug tests, and pump tests (Bechtel National, Inc. 1987; MK-Ferguson Company and Jacobs Engineering Group, Inc. 1990a). The hydraulic conductivity values determined from packer tests ranged from 3.5×10^{-7} to 6.3×10^{-2} cm/s (0.001 to 179 ft/d); those from slug tests ranged from 1.7×10^{-6} to 4.5×10^{-3} cm/s (0.005 to 12.8 ft/d); and those from pumping tests, which were conducted in three different regions of the chemical plant area, ranged from 5.3×10^{-6} to 8.9×10^{-5} cm/s (0.015 to 0.25 ft/d). These results indicate that the hydraulic conductivity of the shallow aquifer at the chemical plant area is highly variable. The higher conductivities generally were associated with wells open to the upper portion of the shallow aquifer. Most of the higher values for hydraulic conductivity were derived from packer and slug tests conducted in the wells open to the weathered zone of the Burlington-Keokuk and located in the northern and western portions of the chemical plant area. This region of higher hydraulic conductivity may provide a preferred flow path for migration of groundwater contaminants. Detailed information on the aquifer tests at the chemical plant area can be found in the RI report for the chemical plant area (DOE 1992d) and in several other reports (Bechtel National, Inc. 1987; MK-Ferguson Company and Jacobs Engineering Group, Inc. 1990a).

Slug tests were performed on 40 wells at the ordnance works area. The hydraulic conductivities determined from these tests ranged from 2.1×10^{-8} to 2.8×10^{-5} cm/s (6.0×10^{-5} to 7.9×10^{-2} ft/d). Similar to the data collected at the chemical plant area, the higher results for hydraulic conductivity were generally obtained from wells completed within the weathered unit of the Burlington-Keokuk. Detailed information on the aquifer tests can be found in the RI report for the training area (IT Corporation 1993a). The results of the aquifer testing at the ordnance works area indicate that the shallow limestone has diffuse flow similar to the chemical plant area (IT Corporation 1993a), except where subsurface conduits exist (e.g., Burgermeister Spring valley).

The Missouri Department of Natural Resources has conducted two shallow groundwater investigations, one at the chemical plant area and the other at the training area (Missouri Department of Natural Resources 1991; Price 1991). The area of study for both of these investigations also included the ordnance works area. The primary objective of the studies was to identify the shallow groundwater discharge points around the training area and the chemical plant area that might be affected by runoff from these two areas. The investigations included classification of surface drainage into losing and gaining segments, water-tracing tests, and continuous water-level monitoring of selected wells.

The results of the investigations indicate that water movement in the upper aquifer has been affected by karst development from solution activity in the carbonate bedrock around the chemical plant area and the training area. The numerous springs and losing streams and the several sinkholes that were identified at the ordnance works area suggest this conclusion; the results of the tracer tests provide further supporting evidence (Missouri Department of Natural Resources 1991; Price 1991).

Specifically, the results of the water-tracing tests illustrated in Figure 2.6 show two general patterns. Dye injected into a drainage of the Missouri River watershed (the southern part of the ordnance works area) was recovered in the same drainage farther downstream, indicating that water in one watershed does not cross into another. The only exception to this pattern was dye injections at the south-flowing headwaters of the 5100 watershed. These injections were recovered farther downstream and also in the north-flowing drainage designated 6100. This finding indicates that the groundwater divide in this area no longer parallels the surface water divide.

The other general pattern is that dye injected into the tributaries of Dardenne Creek, a drainage of the Mississippi River watershed, was recovered at springs in adjoining drainages. Traces that were injected into Schote Creek or its tributaries at springs were recovered in a separate surface water drainage to the north. This pattern was found for surface water in the Schote Creek drainage basin (6200), which recharges groundwater, crosses under a surface-water divide, and emerges in Burgermeister Spring valley (6300). Similarly, in the northwestern part of the ordnance works area, dye injected into the 6500 drainage was recovered in three other surface drainages.

On the basis of the tracer tests, the springs that are recharged by runoff from the chemical plant area are in drainages 5300 (Southeast Drainage) and 6300 (Burgermeister Spring valley). The springs that are potentially affected by either runoff or infiltration from the training area are in drainages 5500, 5600, 6300 (Burgermeister Spring valley), 6500, and 6600. In addition to these drainages, drainage 5400 may also be affected by either runoff or infiltration because of its proximity to the two areas. Drainages 5100 and 5200 may be affected because burning grounds associated with past operations at the ordnance works area are located in these drainages.

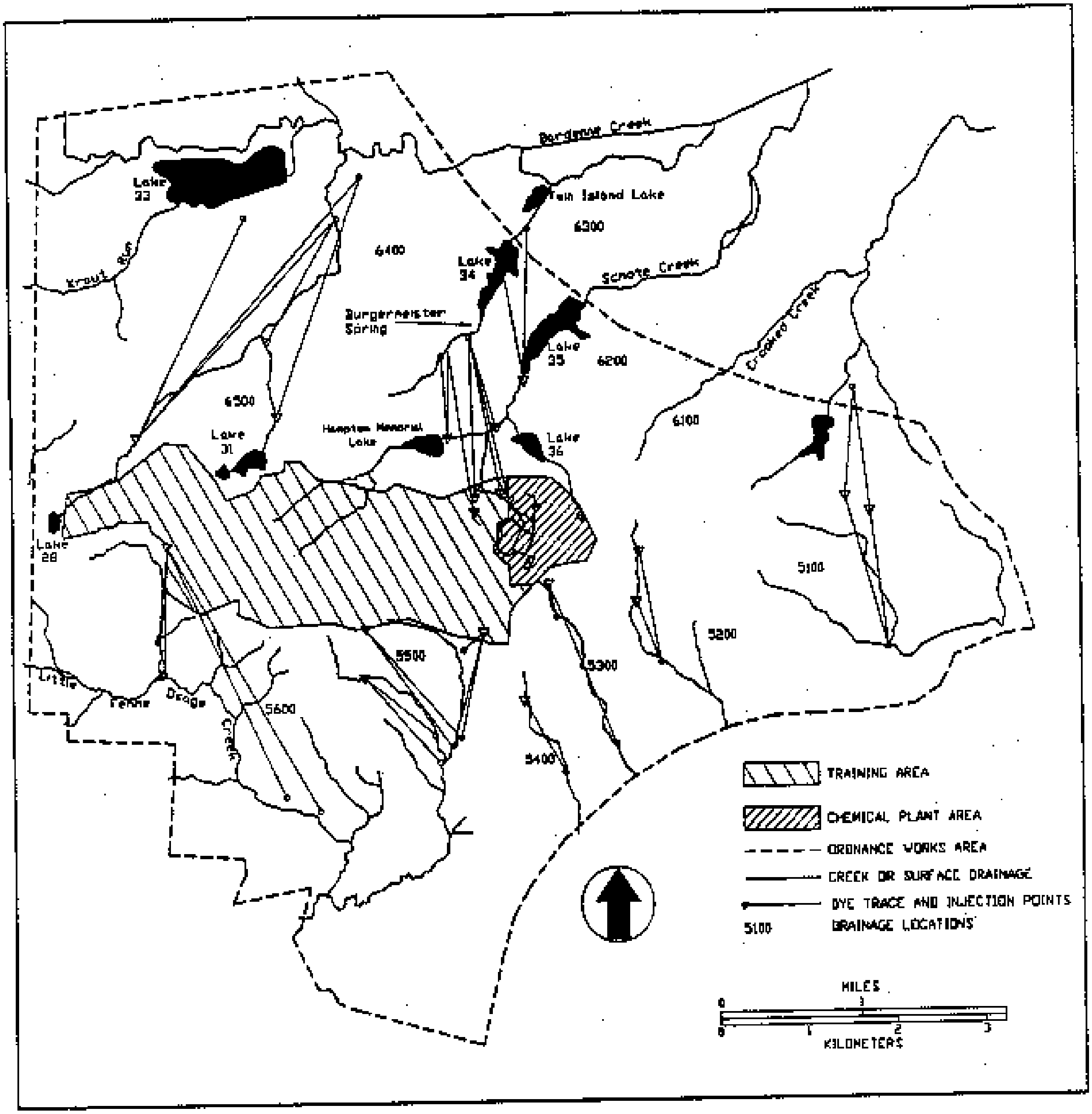


FIGURE 2.6 Water-Tracing Tests Performed at the Ordnance Works Area

The shallow aquifer beneath the ordnance works area and the chemical plant area is part of a carbonate system. This shallow aquifer system is characterized by the presence of thickly bedded limestones, a number of losing stream segments and sinkholes, swallow holes, conduits that discharge to springs, a pronounced groundwater trough in the map of the water-table elevation, solution-broadened joints and fractures, and extensively weathered bedrock. Conceptually, two regimes of groundwater flow can exist in this shallow carbonate groundwater system: diffuse flow and discrete flow. Diffuse groundwater flow occurs where the porous medium is unweathered or where the bedrock is thinly bedded or fractured sufficiently to serve as a uniform porous medium. Discrete groundwater flow (high-velocity turbulent flow that does not obey Darcy's law for a porous medium) occurs in conduits and in large, isolated fractures.

A small number of subsurface conduits have been identified within the ordnance works area north and south of the training area (Missouri Department of Natural Resources 1991; Price 1991). One of these conduit pathways coincides with the trough in the water-table surface shown in Figure 2.5. This conduit rapidly transfers water from a swallow hole or losing stream segment to Burgermeister Spring. Within conduits, flow is discrete (i.e., high-velocity, often turbulent flow through series of irregular, connected pipes or open channels [White 1988]). Outside of the conduits (e.g., upland areas in the training area and most of the ordnance works area), groundwater flow is diffuse (low-velocity, laminar flow that obeys Darcy's law).

The chemical plant area shows evidence of the regional carbonate groundwater system (i.e., weathered bedrock and solution-broadened joints and fractures), but no conduits that connect the chemical plant area with an associated discharge spring have been found by the Missouri Department of Natural Resources (1991). Despite the lack of identified conduits, overland flow from the chemical plant area may be lost via a losing reach of an unnamed tributary of Schote Creek about 300 m (1,000 ft) northwest of Ash Pond and via a swallow hole in Schote Creek (Missouri Department of Natural Resources 1991; DOE 1992d). The results of two water-tracing studies (Missouri Department of Natural Resources 1991) indicate that a subsurface conduit exists between the unnamed tributary of Schote Creek and Burgermeister Spring. The travel time for the 1,980-m (6,494-ft) straight-line distance from the losing branch of the unnamed tributary to Burgermeister Spring is estimated to be 48 to 72 hours, depending on antecedent rainfall. The travel time for the 1,067-m (3,500-ft) straight-line distance from the swallow hole in Schote Creek to Burgermeister Spring is about five to eight hours.

Four losing stream segments and one swallow hole were identified by the Missouri Department of Natural Resources (1991) in the Southeast Drainage in the Missouri River watershed during a controlled discharge test with downstream monitoring and videotaping. Flow lost at the swallow hole (SH-5301) at the head of the first losing stream segment reappeared downstream at spring SP-5301. Flow from this spring was then lost to the creekbed and reappeared at SP-5302. This process continued for the length of the valley. No loss of water to outside of the drainage was observed. In addition, water-tracing studies performed with pyranine dye provided additional support that water introduced into the

Southeast Drainage stayed within it and traveled from spring to spring within underground solution features (Missouri Department of Natural Resources 1991).

2.3.4 Ecological Resources

The ordnance works area supports a diverse flora. Upland forest trees include oaks and shagbark hickory. Slopes of streams typically include oak and hickory, as well as species common to mesic sites, including sugar maple, American elm, and black walnut. Floodplains, creek bottoms, and banks of lakes support willow, cottonwood, silver maple, elm, hackberry, and box elder. Other prominent habitat types of the ordnance works area include old fields and pastures. Typical plants of old fields include grasses, goldenrod, asters, Canada thistle, mustards, and ragweed (IT Corporation 1993a). The northern portion of the training area is sparsely wooded with scattered open grassy fields, whereas the southern portion is more rugged and more heavily wooded. Old roadways throughout the training area are becoming overgrown with trees and shrubs.

The remainder of the former ordnance works area is occupied by the chemical plant area, the Busch Conservation Complex, the University of Missouri Research Park, the Francis Howell School District, and a private housing development (see Section 2.1.1). The chemical plant area is adjacent to the eastern edge of the training area and supports a variety of managed and unmanaged habitats. The Busch Conservation Complex, which consists of the August A. Busch Memorial Conservation Area and the Weldon Spring Conservation Area, is actively managed for wildlife by the Missouri Department of Conservation.

The Busch Conservation Complex contains a wide variety of terrestrial and aquatic habitats and supports a diverse biota. More than 277 species of birds, 29 species of mammals, 47 species of reptiles, 25 species of amphibians, and 100 species of fish have been reported from St. Charles County — many of which occur at the Busch Conservation Complex (Missouri Department of Conservation 1989, 1991; Dickneite 1988). A detailed description of the vegetation, fish and wildlife, and habitats of the Busch Conservation Complex is presented in the baseline assessment (BA) for the chemical plant area (DOE 1992a).

The principal surface water feature of relevance to this RI/FS work plan is Burgermeister Spring. This spring is located in the former ordnance works area north of the chemical plant in an area of upland forest with a relatively dense understory. Tree species present in this area include red oak, persimmon, Kentucky coffee tree, and cottonwood. Ground cover immediately around the spring is dominated by periwinkle, whereas the shrubby understory is predominantly honeysuckle. At Burgermeister Spring, groundwater discharges into a square concrete enclosure about 1.5 m (4.9 ft) on each side and about 0.5 m (1.6 ft) high. The floor of the enclosure is clean sand and gravel, through which groundwater discharge is evident. Spring water within the enclosure flows through a crack in the concrete wall into a small natural stream channel (about 1 m [3.2 ft] wide). A small concrete weir is located about 15 m (50 ft) downstream of the spring, creating a small pool (about 2 m × 3 m [7 ft × 9 ft] and about 0.3 m [1 ft] deep) with a sand/silt bottom. Below the weir, the stream flows over a sand, gravel, and cobble substrate for about 15 m (50 ft) and then joins a larger stream that flows into Lake 34 about 1 km (0.6 mi) downstream of the spring.

No fish occur above the weir, which effectively serves as a barrier to the upstream passage of fish. The fish community of Burgermeister Spring below the weir is typical of midwestern headwater streams; and reported species include the orangethroat darter, green sunfish, brook silverside, and redfin shiner. The larger stream that receives inflow from the spring and discharges to Lake 34 supports a more diverse fish fauna, including species common to Lake 34 that may use the stream as spawning and nursery habitat. Fish using the stream may include the black and white crappie, green sunfish, bluegill, largemouth bass, carp, and black bullhead.

Common mammal species in the Weldon Spring area that may occur in the vicinity of Burgermeister Spring include fox and gray squirrels, white-tailed deer, opossum, raccoon, skunk, mice, and rodents. Common herpetofauna in the area may include several species of frogs, salamanders, turtles, and snakes. Birds using habitats at the spring may include warblers, sparrows, and songbirds; woodpeckers; barred, great horned, and screech owls; and, in the vicinity of Lake 34, waterfowl and wading birds. Several high-quality natural communities occur in the former ordnance works area (Gaines 1988), but none of them are known to be influenced by groundwater originating from the chemical plant area.

Five federal-listed threatened or endangered species, five federal candidate (C2) species, 13 state endangered species, and 19 state rare species have been reported from St. Charles County (Table 2.2). Federal- or state-listed species reported from or near the Busch Conservation Complex and the former ordnance works area include the bald eagle, pallid sturgeon, paddlefish, sicklefin chub, sturgeon chub, Cooper's hawk, long-tailed weasel, wood frog, eastern massasauga rattlesnake, alligator snapping turtle, decurrent false aster, and arrow arum. No federal-listed threatened or endangered species, candidate species, or critical habitats have been identified by the U.S. Fish and Wildlife Service as occurring at the chemical plant area (Tieger 1988; Nash 1990). Wintering bald eagles roost overnight at the Howell Island Conservation Area and may forage in the former ordnance works area. Although the pallid sturgeon, sicklefin chub, and sturgeon chub have been reported from the Missouri River in the vicinity of the ordnance works area, and the paddlefish from Femme Osage Slough, these four species are restricted to large riverine habitats such as the Missouri River and do not occur in or use Burgermeister Spring.

The Cooper's hawk, long-tailed weasel, and wood frog occur in the Weldon Spring Conservation Area and could use terrestrial habitats in the vicinity of Burgermeister Spring. The eastern massasauga rattlesnake, alligator snapping turtle, arrow arum, and decurrent false aster are not expected to inhabit the Burgermeister Spring drainage. The western sand darter is a state watch-listed species that has been reported from St. Charles County. This species occurs on sand substrates along stream margins and shallow backwaters (Pflieger 1975) and may be present in Burgermeister Spring below its weir.

TABLE 2.2 Threatened, Endangered, or Special-Concern Species Reported from St. Charles County

Species		Status	
Common Name	Scientific Name	Federal[a]	State[b]
Plants			
Adder's-tongue fern	*Ophioglossum vulgatum* var. *pycnostichum*	-	WL
Arrow arum	*Peltandra virginica*	-	R
Bugseed	*Corispermum hyssopifolium*	-	WL
Forbes' saxifrage	*Saxifraga pensylvanica* var. *forbesii*	3C	-
Rose turtlehead	*Chelone obliqua* var. *speciosa*	3C	E
Star duckweed	*Lemna trisulca*	-	R
Decurrent false aster	*Boltonia decurrens*	T	E
Fish			
Alabama shad	*Alosa alabamae*	-	R
Alligator gar	*Lepisosteus spatula*	-	R
Brown bullhead	*Ameiurus nebulosus*	-	R
Paddlefish	*Polyodon spathula*	C2	WL
Pallid sturgeon	*Scaphirhynchus albus*	E	E
Pugnose minnow	*Notropis emiliae*	-	WL
Sicklefin chub	*Macrhybopsis meeki*	C2	R
Starhead topminnow	*Fundulus dispar*	-	WL
Sturgeon chub	*Macrhybopsis gelida*	C2	R
Western sand darter	*Ammocrypta clara*	-	WL
Reptiles and amphibians			
Alligator snapping turtle	*Macroclemys temminckii*	C2	R
Blanding's turtle	*Emydoidea blandingii*	-	E
Eastern massasauga	*Sistrurus catenatus catenatus*	C2	E
Northern crawfish frog	*Rana areolata circulosa*	-	WL
Western fox snake	*Elaphe vulpina vulpina*	-	E
Western smooth green snake	*Opheodrys vernalis blanchardi*	-	E
Wood frog	*Rana sylvatica*	-	R
Birds			
American bittern	*Botaurus lentiginosus*	-	E
Bachman's sparrow	*Aimophila aestivalis*	C2	E
Bald eagle	*Haliaeetus leucocephalus*	E	E
Barn owl	*Tyto alba*	-	R
Black-crowned night heron	*Nycticorax nycticorax*	-	R
Cooper's hawk	*Accipiter cooperii*	-	R
Henslow's sparrow	*Ammodramus henslowii*	C2	R
Interior least tern	*Sterna antillarum*	E	E
Little blue heron	*Egretta caerulea*	-	R
Mississippi kite	*Ictinia mississippiensis*	-	R
Northern harrier	*Circus cyaneus*	-	E
Osprey	*Pandion haliaetus*	-	EX
Peregrine falcon	*Falco peregrinus*	E	EX
Pied-billed grebe	*Podilymbus podiceps*	-	R
Red-shouldered hawk	*Buteo lineatus*	-	WL

TABLE 2.2 (Cont.)

Species		Status	
Common Name	Scientific Name	Federal[a]	State[b]
Birds (Cont.)			
Sharp-shinned hawk	*Accipiter striatus*	-	R
Snowy egret	*Egretta thula*	-	E
Upland sandpiper	*Bartramia longicauda*	-	WL
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*	-	R
Mammals			
Long-tailed weasel	*Mustela frenata*	-	R

[a] E = endangered; T = threatened; C2 = federal candidate for listing as a threatened or endangered species; and 3C = former federal candidate species. A hyphen indicates that no federal status has been established.

[b] E = endangered; EX = extirpated; R = rare; and WL = watch list. Special-concern species include those classified by the state as rare, on the watch list, or status undetermined. The watch list contains species of possible concern for which the Missouri Department of Conservation is seeking further information; this listing does not imply that these species are imperiled. Extirpated means formerly occurred as a regular breeding species but no longer reproduces in Missouri.

Sources: Dickneite (1988); Gaines (1988); Bedan (1991); Figg (1991); the Missouri Department of Conservation (1992).

2.3.5 Archaeological and Historic Resources

The former Weldon Spring Ordnance Works is situated near the Missouri River in an area of limestone mantled with till and aeolian sediment that contains a high density of archaeological remains. All major prehistoric periods spanning the last 11,000 years are represented in sites that typically occur along ridges or streams (Chapman 1975, 1980; Haas 1978). Euro-Americans first entered the region between A.D. 1673 and A.D. 1680 and encountered Algonquin-speaking Native American groups. Although St. Louis was founded in 1764, widespread Euro-American settlement did not begin until after the Louisiana Purchase in 1803 (March 1967). Early Euro-American sites (e.g., farmsteads and cemeteries) are also found in the area (Walters 1990, 1992).

Archaeological sites and historic structures that meet the criteria established for eligibility in the *National Register of Historic Places* would require mitigative action if subject to adverse effects. In 1986, the Missouri State Historic Preservation Officer determined that the Weldon Spring chemical plant area was not eligible for the *National Register* (Weichman 1986). This determination was made on the basis of prior disturbance, low potential for archaeological remains, and possible health risks.

2.3.6 Land Use and Population

The chemical plant area and the ordnance works area are located in St. Charles County, Missouri, which has a population of approximately 100,000. The largest city in the county is St. Charles; it is located about 24 km (15 mi) northeast of the site and has a population of about 50,000.

The former ordnance works area encompassed 7,000 ha (17,232 acres), which has since been divided into several contiguous areas with different ownership and land use (Section 2.1.1). The 700-ha (1,650-acre) Weldon Spring Training Area is adjacent to the 88-ha (217-acre) chemical plant area. Both areas are fenced, and access by the general public is restricted. Portions of the training area that are not contaminated are currently used for field training and outdoor drilling by the U.S. Army Reserve, the Missouri Army National Guard, and other military and police units. An estimated 3,300 local Army reservists and 3,400 other reserve troops use the training area each year (Daubel 1992). The Army intends to continue using the training area for training activities in the future.

A large portion of the ordnance works area has been converted into conservation areas. The 2,828-ha (6,987-acre) August A. Busch Memorial Conservation Area and the 2,977-ha (7,356-acre) Weldon Spring Conservation Area are managed by the Missouri Department of Conservation and are open throughout the year for recreational use. These areas receive an estimated 1,200,000 visitors each year (Crigler 1992).

A state highway maintenance facility is located just east of the chemical plant area. The facility employs nine full-time staff and one mechanic (Sizemore 1991). The former staff housing complex for the former ordnance works, located southeast of the intersection of State Route 94 and U.S. Route 40/61, is currently a private housing development known as the Weldon Spring Heights, with a population of about 80.

Francis Howell High School is located about 1 km (0.6 mi) east of the chemical plant area. The school employs approximately 175 faculty and staff (including employees at the Francis Howell Administration Annex) and is attended by about 1,930 students (Meyer 1993).

2.4 NATURE AND EXTENT OF CONTAMINATION

2.4.1 Origin of Contamination

The areas included in the two GWOUs are radioactively and chemically contaminated as a result of past processing activities conducted by the Army and the AEC. During the 1940s, the Weldon Spring Ordnance Works was owned and operated by the Army for the production of explosives. During peak production, approximately 149,000 t (164,000 tons) of explosives was produced annually. The ordnance works consisted of 18 TNT and two DNT explosives production lines situated within the current boundaries of the training area and the adjoining chemical plant area. The first manufacturing facilities were built on what is now the chemical plant area, and construction progressed from east to west across the training area. Each TNT manufacturing line consisted of a mono-, di-, and trinitrating house where toluene was nitrated in three consecutive stages. Crude TNT was purified by washing with a sellite solution in a washhouse, followed by melting, dewatering, and recrystallization of purified TNT at a grainer house. Grained TNT was then transported to the pack house, where the final product was screened and packaged for shipping. The DNT production lines consisted of a nitrating house where DNT was produced and a sweating house where crude DNT was repeatedly heated and cooled in a "sweat pan" to drive off any impurities. Upon purification, the molten DNT was then transferred to a water-cooled kettle where graining occurred. The final crystalline powder product was screened and packaged for storage and shipment.

The processing activities involved millions of gallons of water per day for washing and mixing chemicals. Prior to construction of the wastewater treatment plants, the red and yellow wastewaters were discharged via pipelines to lagoons for temporary storage. After 1943, the lines discharged into wastewater treatment plants where the wastewaters were evaporated into sludge. The sludges were burned in incinerators located at the treatment plant sites, and liquid effluents from the treatment plants were discharged to the Missouri River via the 5300 drainage.

The primary contaminants associated with the ordnance works are the nitroaromatic chemicals that were manufactured — TNT and DNT — and their decomposition products. Lead, which was used extensively to provide nonsparking metal surfaces in production areas, is also a potential contaminant. The major manufacturing chemicals used were toluene, nitric acid, sulfuric acid, and sellite (sodium sulfite). Major source areas associated with the ordnance works include the TNT and DNT production lines, wastewater treatment plants, in-line settling tanks, sellite/acid plants, burning grounds, laboratory building, Mechanical City (former construction and maintenance area for the ordnance works), bunkers, regraining area, underground pipeline, dumps, and lagoons. These areas are depicted in Figure 2.2.

The Weldon Spring Uranium Feed Materials Plant was operated by the AEC from 1957 to 1966. The plant processed an average of 14,000 t (16,000 tons) of uranium material per year. A small amount of thorium ore was also processed. Plant operations generated several radioactive and chemical waste streams, including raffinates from the refinery operations and magnesium fluoride slurry (washed slag) from the uranium recovery process. These waste streams were piped to the raffinate pits, where the solids settled out; and the supernatant liquids were decanted to the plant process sewer, which drained to the 5300 drainage. The contaminants potentially associated with the processing activities include those radionuclides in the uranium-238, thorium-232, and uranium-235 decay series; metals that may be associated with the ores (e.g., arsenic, copper, cobalt, lead, manganese, molybdenum, nickel, selenium, vanadium, and zinc); and various process chemicals. The chemicals used for processing included nitric, sulfuric, and hydrofluoric acids; hexane; tributylphosphate; magnesium; sodium carbonate; and sodium hydroxide. The contaminated areas that resulted primarily from the uranium-processing activities include the raffinate pits, Ash Pond, Frog Pond, north and south dumps, and the chemical plant buildings. These source areas are depicted in Figure 2.3.

2.4.2 Summary and Evaluation of Data

Data that provide information regarding horizontal and vertical contaminant profiles in the shallow groundwater system have been compiled and evaluated for this work plan. For both the chemical plant area and the ordnance works area, data are available from a series of wells that are currently in place as monitoring wells. The number and locations of these monitoring wells are generally adequate to characterize groundwater flow for the purpose of an RI/FS. In a few locations, additional wells are required to complete the groundwater flow conceptual model and confirm the extent of contamination. These wells have been identified as a data requirement (see Section 3.5). In this work plan, data are evaluated from 75 wells that DOE has sampled at the chemical plant area and 69 wells that CE has sampled at the ordnance works area (including the training area). At the chemical plant area, nine wells were abandoned as a result of construction activities in support of on-site disposal. Currently, at the ordnance works area, four of the 69 wells are also no longer sampled, either because the pump is inoperable, the completion interval is too deep, or the hole is plugged.

Under the DOE environmental monitoring program, groundwater and surface water data have been collected by the Project Management Contractor since 1987 at the chemical plant area and adjacent areas, the Southeast Drainage, and Burgermeister Spring. Monitoring data have been entered into a computerized database referred to as the *Weldon Spring Site Remedial Action Project (WSSRAP) Information System for Archiving and Reporting Data* (WIZARD). This database is the primary source for the summaries of chemical plant groundwater and surface water data presented in Sections 2.4.4.

Under the CE monitoring program, groundwater and surface water data have been collected quarterly since 1989 by IT Corporation at the ordnance works area and Burgermeister Spring. The RI report for the training area and quarterly monitoring reports are the primary sources for the summary of ordnance works groundwater data presented in Section 2.4.5 (IT Corporation 1992a-d, 1993a-e, 1994a-c). The summary of data for Burgermeister Spring in Section 2.4.6 is based on both DOE and CE sources because both programs have monitored springs.

For the chemical plant area, data collected from June 1990 to December 1993 have been included for quantitative discussion because they most accurately reflect current groundwater conditions. Data prior to 1990 have been incorporated into the discussion in a more qualitative manner because review of the data from the chemical plant area indicated that many of the suspected outliers were measured in groundwater and surface water samples prior to 1990. Suspected outliers are defined as values exceeding the expected range; these values may be the result of sampling or analytical errors. The expected range in this context is calculated to be three standard deviations above the mean. Ongoing data evaluation will include further analysis of suspected outliers for inclusion in or exclusion from future assessments.

The focus of the GWOUs is the shallow groundwater system represented primarily by wells completed in the Burlington-Keokuk Limestone. Stratigraphic zones have been identified within the Burlington-Keokuk on the basis of weathering characteristics (Section 2.3.2). To assess the vertical and lateral distribution of contaminants at both the chemical plant area and the ordnance works area, the open intervals of the Burlington-Keokuk monitoring wells have been correlated with an upper weathered zone overlying a deeper unweathered unit within the limestone aquifer. The open interval for a number of wells includes both zones (i.e., part of the well is open across the weathered unit and part across the unweathered unit). These wells have been grouped with the weathered wells because their measured water-level elevations are more representative of the shallow, weathered zone.

The constituents that have been measured in samples from the chemical plant area and the ordnance works area include nitroaromatics, radionuclides, metals, and inorganic anions. The nitroaromatics are anthropogenic (i.e., synthetic) substances; therefore, any nitroaromatics detected in site samples may be assumed to be related to past processing activities. Conversely, the radionuclides, metals, and inorganic anions are all naturally occurring materials that would be expected to be present in groundwater, surface water, and sediment samples at levels determined by the composition of the host rock or unconsolidated materials from which the samples were obtained; however, some of the radionuclides, metals, and inorganic anions are also associated with past processing activities.

For naturally occurring substances, concentrations in environmental media at hazardous waste sites are often compared with background concentrations (i.e., levels at locations known to be unaffected by previous site activities) to determine if site levels are related to past operations. For this work plan, groundwater data for the chemical plant area and the ordnance works area were compared with background concentrations in a preliminary general way; however, groundwater concentrations were also compared with EPA criteria for public drinking water supplies, in order to address the question of whether levels are of concern with respect to human health. The EPA criteria used are maximum contaminant levels (MCLs), which are primarily based on human health considerations but may also consider treatment technologies and cost; secondary maximum contaminant levels (SMCLs), which are based on aesthetic water-quality considerations; and maximum contaminant level goals (MCLGs), which are nonenforceable levels that are protective of human health and allow an adequate margin of safety.

The MCL, SMCL, and MCLG criteria are applicable for comparison with groundwater concentrations at the chemical plant area and the ordnance works area because these criteria have been promulgated for drinking water supplies, which is the most conservative possible future use of the groundwater. These groundwater criteria levels are compared with concentrations detected in monitoring wells in the chemical plant and ordnance works areas to aid preliminary identification of groundwater constituents that may present human health risks and also to identify those constituents that are unlikely to be associated with human health risks.

For ecological risk considerations, the approach used to screen contaminant concentrations in surface waters collected from Burgermeister Spring was similar to that used to screen the contaminants for human health considerations, except that EPA ambient water quality criteria (AWQC) were used in place of MCLs or SMCLs. For those contaminants for which no AWQC exist, measured concentrations were compared with the concentrations reported in the scientific literature for lowest observed adverse effects or no observed adverse effects (DOE 1992a).

For the ordnance works area, metal analyses for all sampling rounds were conducted for both filtered and unfiltered samples. Additionally, some radionuclide and metal analyses were conducted for unfiltered samples from monitoring wells in the chemical plant area, but most groundwater data for the chemical plant area are from filtered samples. Concentrations of naturally occurring substances in unfiltered groundwater samples may be more indicative of the host materials at the well location than of the actual water quality. Because of the high concentrations of certain metals and inorganic anions occurring naturally in groundwater at the chemical plant and ordnance works areas, this water likely would be filtered if used as a drinking water source; however, groundwater from private wells could be used without prior filtration, so data from unfiltered samples is also relevant for the evaluation of potential health effects. Therefore, both filtered and unfiltered samples were considered in comparing chemical plant and ordnance works groundwater concentrations with EPA criteria.

2.4.3 Background Concentrations of Naturally Occurring Constituents

Radionuclides, metals, and inorganic anions are naturally occurring materials in groundwater. To estimate the concentrations expected to occur naturally in groundwater at the ordnance works area and the chemical plant area, several wells were identified as potential background wells at locations not thought to be associated with past processing activities. Wells selected as representative of the weathered zone of the Burlington-Keokuk Limestone are MWS 13, MWS 23, and MWS 111; wells selected as representative of the unweathered zone of the Burlington-Keokuk are MWD 105, MWD 106, MWS 108, and MWD 109 (see Section 2.4.5 and Figure 2.7 for well locations). No nitroaromatic compounds have been detected in these wells, which supports the assumption that the locations of these wells are not in areas affected by past processing activities; however, concentrations of manganese and sulfate in wells MWS 111 and MWS 113, respectively, appear to be higher than those at most other locations. The result of the joint sampling effort will be used to reevaluate the selected background wells as part of the RI.

Concentrations of metals and inorganic anions in these background wells are summarized in Tables 2.3 and 2.4. Uranium levels in these wells have not been measured; however, data for uranium were obtained as part of the joint sampling effort. Background data for uranium will be evaluated and discussed in the RI.

2.4.4 Groundwater at the Chemical Plant Area

The current DOE groundwater-monitoring network in the vicinity of the chemical plant area consists of 66 monitoring wells, all of which are open to the Burlington-Keokuk Limestone that constitutes the shallow groundwater system. The monitoring network includes 57 wells that are used for environmental surveillance and nine wells used to monitor groundwater at the temporary storage area and the site water treatment plant equalization basin. Of the 57 wells, 27 are on-site wells (2000 series), eight are in the vicinity of the raffinate pits (3000 series), and 22 are adjacent to the fenced boundary of the chemical plant area (4000 series). The monitoring well network is shown in Figures 2.7 and 2.8. The data evaluation process for the chemical plant area included data from all monitoring wells (i.e., current monitoring network and abandoned or inactive wells).

To facilitate evaluation of the vertical distribution of contamination, monitoring wells at the chemical plant area were grouped by open interval in the Burlington-Keokuk Limestone (i.e., weathered and unweathered) (Section 2.3.2). Of the 66 wells, 48 monitor only the weathered unit or both the weathered unit and part of the unweathered unit, and 18 monitor the unweathered unit of the Burlington-Keokuk Limestone (Table 2.5).

From 1987 to 1990, groundwater monitoring at the chemical plant area generally consisted of quarterly sampling of the entire monitoring well network. In 1990, the monitoring frequency was reduced to semiannually at monitoring locations where contaminants exceeded water quality standards and was reduced to annually at the remaining locations. Monitoring wells that have been recently installed are currently being sampled quarterly.

Most of the groundwater analyses for the chemical plant area have been performed on filtered samples. Groundwater samples are generally filtered through a 0.45-µm membrane filter as part of site environmental monitoring procedures. A limited number of analyses were also performed on unfiltered samples collected from a subset of monitoring wells. The data for filtered and unfiltered samples are presented separately in this work plan.

Filtering the groundwater samples before metals analysis occurs could result in the removal of metals not in the solution phase, thereby resulting in underestimation of the concentrations of metals (Puls and Barcelona 1989; Puls et al. 1992). Differences between measurements on filtered and unfiltered samples depend on the solubility of specific contaminants and the tendency of the contaminants to be adsorbed on solid particles. Chemical species with high solubility — such as calcium, magnesium, potassium, sodium, and some inorganic anions — might be less affected by the process of filtration. The effects of filtration have been considered in the data evaluation process.

The discussion of radioactive and chemical contamination in Sections 2.4.4.1 and 2.4.4.2 is based on the range and mean concentrations of parameters detected in filtered and unfiltered samples obtained from the monitoring well network from June 1990 to December

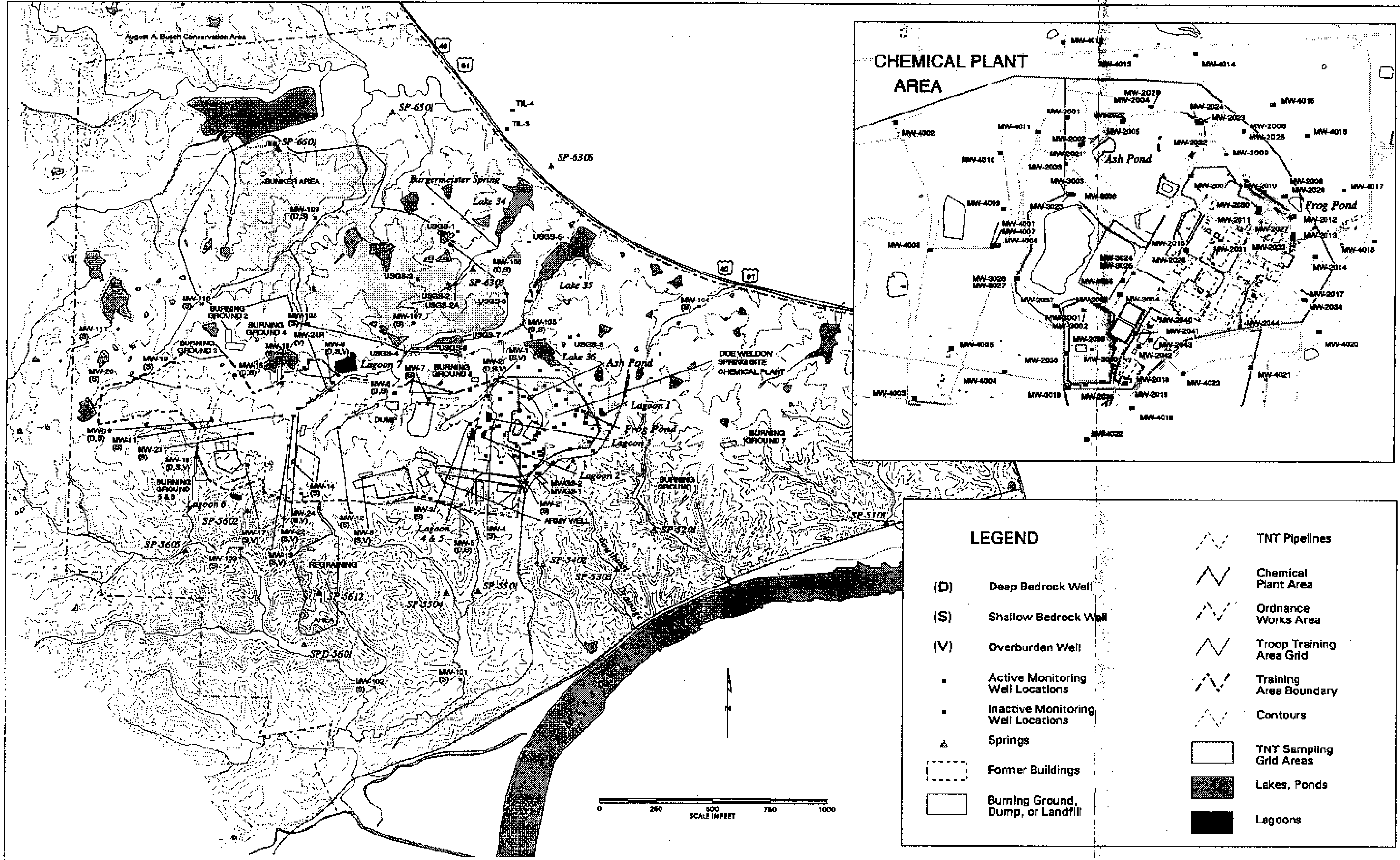


FIGURE 2.7 Monitoring Locations at the Ordnance Works Area and the Chemical Plant Area

TABLE 2.3 Summary of Filtered Groundwater Data for Background Wells[a]

Parameter	Weathered Wells[b] Detection Frequency	Range	Mean	Sample S.D.	Upper End	Unweathered Wells[b] Detection Frequency	Range	Mean	Sample S.D.	Upper End
Metals (μg/L)										
Aluminum	7/20	18-360	58	82	220	7/32	18-2,000	100	350	800
Antimony	7/20	1.7-140	19	39	97	9/32	1.7-140	31	51	130
Arsenic	4/21	0.50-20	3.6	4.9	13	6/32	0.50-10	2.2	1.9	6
Barium	21/21	19-410	170	140	450	32/32	81-200	130	25	180
Beryllium	0/20	0.20-3.0	1	0.9	2.8	1/32	0.20-4.0	1.2	1	3.2
Cadmium	7/21	0.20-10	1.7	2.5	6.7	5/32	0.20-10	2	2.9	7.8
Calcium	21/21	43,000-330,000	150,000	110,000	370,000	32/32	510-68,000	55,000	12,000	79,000
Chromium	0/21	2.0-10	4.7	2.9	11	2/32	2.0-10	4.3	2.5	9.3
Cobalt	1/20	2.3-33	8.2	8.0	24	3/32	2.3-33	11	10	31
Copper	4/20	1.0-6.0	3.6	2.2	8.0	7/32	1.0-11	4	3	10
Iron	9/20	6.8-290	41	65	170	21/32	7.0-1,400	95	240	580
Lead	6/21	0.70-88	8.3	19	46	5/32	0.70-88	15	29	73
Lithium[c]	-	-	-	-	-	-	-	-	-	-
Magnesium	21/21	4,000-41,000	27,000	13,000	53,000	32/32	25,000-45,000	35,000	5,600	46,000
Manganese	16/20	2.0-120	29	39	110	32/32	7.0-180	65	54	170
Mercury	2/21	0.10-1.0	0.20	0.20	0.60	2/32	0.10-0.50	0.2	0.09	0.38
Molybdenum[c]	-	-	-	-	-	-	-	-	-	-
Nickel[d]	6/20	5.6-920 (51)	59	200	460 (33)	1/32	5.6-51	16	14	44
Potassium	21/21	900-3,600	2,200	780	3,800	9/32	900-2,000	1,600	460	2,500
Selenium	1/21	0.80-20	2.7	4.6	12	2/32	0.80-10	2.5	3.2	8.9
Silver	0/21	2.0-10	4.9	2.7	10	1/32	2.0-10	4.7	2.5	9.7
Sodium	21/21	3,400-40,000	16,000	14,000	44,000	32/32	5,000-19,000	7,900	3,400	15,000
Thallium[e]	0/17	1.0-4.0	2.0	1.0	4.0	3/24	0.90-4.0	2.0	1.0	4.0
Vanadium	3/20	2.0-14	5.3	3.1	12	3/32	2.0-14	6.1	3.8	14
Zinc	12/20	1.0-100	32	32	96	20/32	1.0-103	32	35	100
Inorganic anions[c] (mg/L)										
Chloride	-	-	-	-	-	-	-	-	-	-
Fluoride	-	-	-	-	-	-	-	-	-	-
Nitrate	-	-	-	-	-	-	-	-	-	-
Sulfate	-	-	-	-	-	-	-	-	-	-

[a] To facilitate comparison with site levels, statistics given assume concentrations equal to the sample detection limits for values reported as not detected. Upper-end values are equal to the mean plus two standard deviations (S.D.). Values are rounded to two significant figures.

[b] Background wells for the weathered zone: MWS 13, MWS 23, and MWS 111; and for the unweathered zone: MWD 105, MWD 106, MWS 108, and MWD 109.

[c] Filtered samples from background wells were not analyzed for lithium, molybdenum, and inorganic anions.

[d] The value in parentheses in the range column is the next to highest value for the range; the highest value is a suspected outlier. (The 924-μg/L value for nickel in MWS 111 was from a duplicate sample; the other value was reported as not detected. Six of seven other sampling rounds reported nickel as not detected; a concentration of 10 μg/L was reported in round 8.) The value in parentheses in the upper-end column is calculated excluding the outlier.

[e] Nondetected values for thallium that exceeded 100 μg/L were excluded, as follows: weathered group, three values excluded; and unweathered group, eight values excluded

TABLE 2.4 Summary of Unfiltered Groundwater Data for Background Wells[a]

Parameter	Weathered Wells[b]					Unweathered Wells[b]				
	Detection Frequency	Range	Mean	Sample S.D.	Upper End	Detection Frequency	Range	Mean	Sample S.D.	Upper End
Metals (μg/L)										
Aluminum	20/21	18-44,000	4,500	9,400	23,000	31/32	20-3,400	800	840	2,500
Antimony	1/21	2.0-140	20	38	96	3/32	2.0-140	33	50	130
Arsenic	8/21	0.90-20	5.2	5.9	17	7/32	0.50-10	3.0	3.0	9
Barium[c]	21/21	22-1,600	280	360	1,000	32/32	81-14,000 (310)	580	2,400	5,400 (210)
Beryllium	0/21	0.20-3.0	0.90	0.80	2.5	1/32	0.20-3.0	1	0.8	2.6
Cadmium	12/21	0.20-10	1.9	2.9	7.7	8/32	0.20-10	2.1	2.9	7.9
Calcium	21/21	46,000-320,000	160,000	100,000	360,000	32/32	48,000-150,000	65,000	17,000	99,000
Chromium	5/21	2.0-42	7.8	9.0	26	3/32	2.0-10	4.5	2.6	9.7
Cobalt	11/21	2.0-41	11	9.0	29	6/32	2.0-33	11	10	31
Copper	14/21	1.0-58	14	16	46	13/32	1.0-62	6	10	26
Iron	21/21	140-68,000	7,100	15,000	37,000	32/32	29-4,100	910	910	2,700
Lead	14/21	2.0-88	11	19	49	10/32	1.5-88	16	28	72
Lithium[d]	-	-	-	-	-	-	-	-	-	-
Magnesium	21/21	4,300-89,000	32,000	20,000	72,000	32/32	25,000-70,000	38,000	9,000	56,000
Manganese[e]	21/21	45-27,000 (9,000)	2,100	6,000	14,000 (4,800)	32/32	13-290	110	72	250
Mercury	2/21	0.10-2.0	0.30	0.50	1.3	2/32	0.10-0.30	0.2	0.07	0.34
Molybdenum[d]	-	-	-	-	-	-	-	-	-	-
Nickel	12/21	8.0-120	21	24	69	5/32	6.0-51	17	14	45
Potassium	17/21	900-3,400	2,300	700	3,700	8/32	900-2,000	1,500	500	2,500
Selenium	1/21	0.80-20	3.0	5.0	13	3/32	0.80-10	3	3	9
Silver	1/21	2.0-22	6.0	5.0	16	0/32	2.0-10	5	3	11
Sodium	21/21	3,400-42,000	16,000	15,000	46,000	32/32	27-18,000	7,600	3,400	14,000
Thallium[f]	0/19	0.0040-30	3.5	6.7	17	2/24	0.90-7.0	2.2	1.5	5.2
Vanadium	12/21	2.0-94	12	19	50	7/32	2.0-14	6	4	14
Zinc	17/21	5.0-480	71	98	270	23/32	6.0-490	51	86	220

TABLE 2.4 (Cont.)

Parameter	Weathered Wells[b]					Unweathered Wells[b]				
	Detection Frequency	Range	Mean	Sample S.D.	Upper End	Detection Frequency	Range	Mean	Sample S.D.	Upper End
Inorganic anions (mg/L)										
Chloride	19/21	0.30-22	4.1	5.1	14	30/32	0.30-18	2.9	4.7	12
Fluoride	15/19	0.10-1.1	0.44	0.26	0.96	25/28	0.10-0.93	0.52	0.26	1.1
Nitrate	2/2	0.29-1.0	0.65	0.50	1.7	2/4	0.010-0.030	0.02	0.01	0.040
Sulfate[g]	16/21	16-840 (22)	240	340	920 (24)	32/32	9.5-61	21	9.9	41

[a] To facilitate comparison with site levels, statistics given assume concentrations equal to the sample detection limit for values reported as not detected. Upper-end values are equal to the mean plus two standard deviations (S.D.). Values are rounded to two significant figures.

[b] Background wells for the weathered zone: MWS 13, MWS 23, and MWS 111; and for the unweathered zone: MWD 105, MWD 106, MWS 108, and MWD 109.

[c] The value in parentheses in the range column is the next to highest value indicated for the range; the highest value is a suspected outlier (barium concentrations in MWD 106 in seven other sampling rounds ranged from 130 to 170 μg/L). The value in parentheses in the upper-end column is calculated excluding the suspected outlier.

[d] Samples were not analyzed for lithium and molybdenum.

[e] The value in parentheses in the range column is the next to highest value indicated for the range; the highest value is a suspected outlier (manganese concentrations in MWS 111 in seven other sampling rounds ranged from 210 to 9,000 μg/L). The value in parentheses in the upper-end column is calculated excluding the suspected outlier.

[f] Nondetected values for thallium that exceeded 100 μg/L were excluded, as follows: weathered group, three values excluded; and unweathered group, eight values excluded.

[g] The value in parentheses in the range column is the highest value when samples from MWS 13 are excluded; the data from this well may not be representative of background for sulfate (seven samples ranging from 540 to 840 mg/L). The value in parentheses in the upper-end column is calculated excluding the suspected outlier.

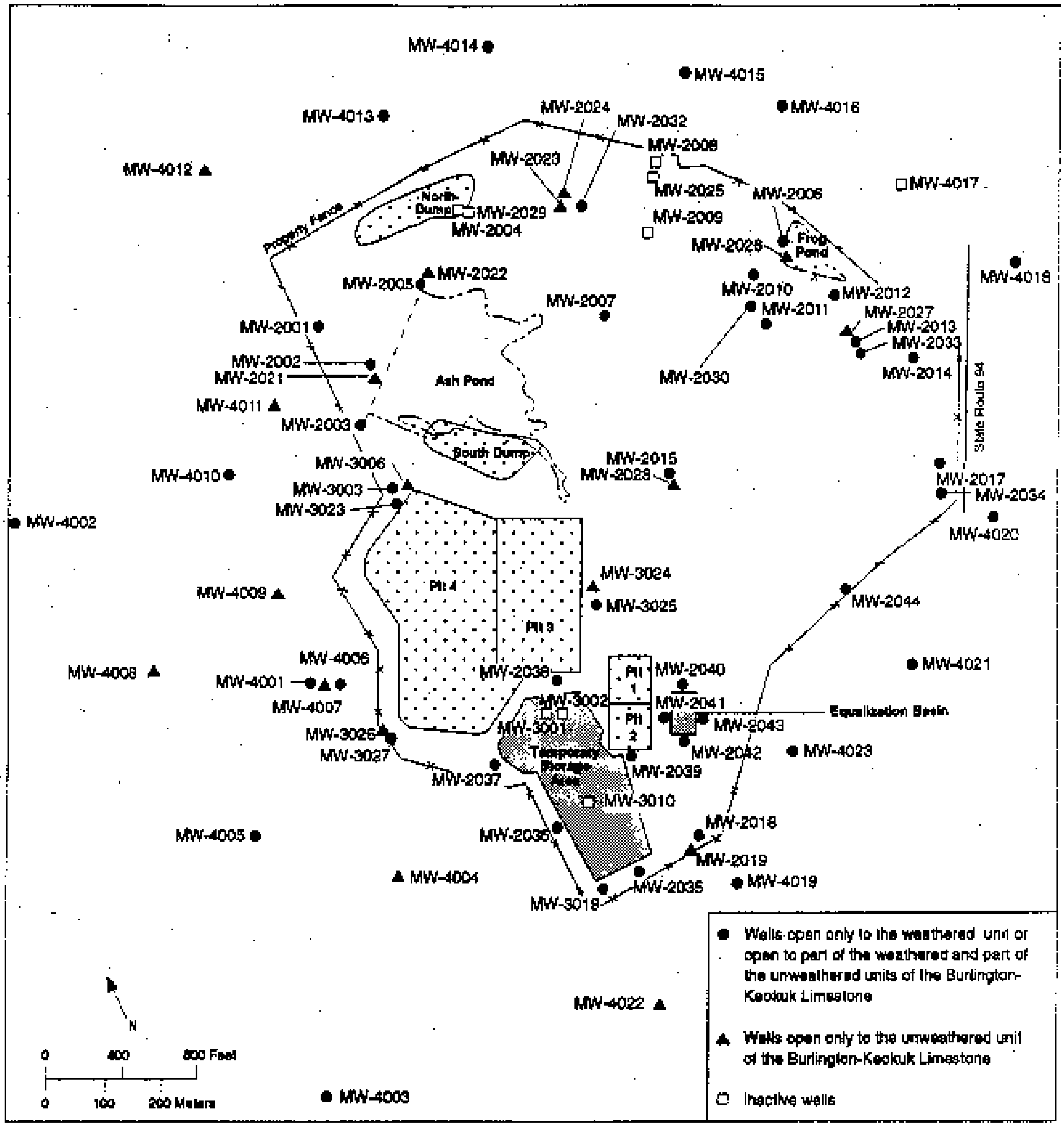


FIGURE 2.8 Monitoring Wells at the Chemical Plant Area and Vicinity

TABLE 2.5 Monitoring Wells for the Groundwater Operable Unit at the Chemical Plant Area

Series/Location/ Well Number	Completion Interval	Series/Location/ Well Number	Completion Interval
2000 Series		*3000 Series*	
Chemical plant area		Raffinate pits	
MW-2001	Weathered/unweathered	MW-3001[a]	Weathered
MW-2002	Weathered	MW-3002[a]	Unweathered
MW-2003	Weathered	MW-3003	Weathered/unweathered
MW-2004[a]	Weathered/unweathered	MW-3006	Unweathered
MW-2005	Weathered	MW-3010[a]	Weathered/unweathered
MW-2006	Weathered/unweathered	MW-3019	Weathered/unweathered
MW-2007	Weathered/unweathered	MW-3023	Weathered
MW-2008[a]	Weathered/unweathered	MW-3024	Unweathered
MW-2009[a]	Weathered	MW-3025	Weathered
MW-2010	Weathered	MW-3026	Unweathered
MW-2011	Weathered/unweathered	MW-3027	Weathered/unweathered
MW-2012	Weathered/unweathered		
MW-2013	Weathered/unweathered	*4000 Series*	
MW-2014	Weathered		
MW-2015	Weathered/unweathered	Off-site wells	
MW-2017	Weathered/unweathered	MW-4001	Weathered/unweathered
MW-2018	Weathered	MW-4002	Weathered/unweathered
MW-2019	Unweathered	MW-4003	Weathered
MW-2021	Unweathered	MW-4004	Unweathered
MW-2022	Unweathered	MW-4005[b]	Weathered/?
MW-2023	Unweathered	MW-4006	Weathered
MW-2024	Unweathered	MW-4007	Unweathered
MW-2025[a]	Unweathered	MW-4008	Unweathered
MW-2026	Unweathered	MW-4009	Unweathered
MW-2027	Unweathered	MW-4010	Weathered/unweathered
MW-2028	Unweathered	MW-4011	Unweathered
MW-2029[a]	Unweathered	MW-4012	Unweathered
MW-2030	Weathered	MW-4013	Weathered/unweathered
MW-2032	Overburden/weathered	MW-4014	Weathered/unweathered
MW-2033	Weathered	MW-4015	Weathered/unweathered
MW-2034	Weathered	MW-4016	Weathered/unweathered
MW-2044	Weathered/unweathered	MW-4017[a]	Weathered/unweathered
		MW-4018	Weathered/unweathered
Temporary storage area		MW-4019	Weathered/unweathered
MW-2035	Weathered/unweathered	MW-4020	Weathered/unweathered
MW-2036	Weathered/unweathered	MW-4021	Weathered/unweathered
MW-2037	Weathered	MW-4022	Unweathered
MW-2038	Burlington-Keokuk[c]	MW-4023	Weathered
MW-2039	Burlington-Keokuk[c]		
Site water treatment plant equalization basin			
MW-2040	Burlington-Keokuk[c]		
MW-2041	Burlington-Keokuk[c]		
MW-2042	Burlington-Keokuk[c]		
MW-2043	Burlington-Keokuk[c]		

[a] Abandoned well.

[b] The lower part of the completion interval is undifferentiated Burlington-Keokuk Limestone.

[c] Assumed to be open to both the weathered and unweathered units of the Burlington-Keokuk Limestone.

1993. The concentrations of the constituents identified in groundwater samples were compared with background concentrations and with criteria established by the EPA (1995) for public drinking water supplies, as discussed in Section 2.4.2. Criteria established by the state of Missouri under the Missouri Safe Drinking Water Act (Missouri Department of Natural Resources 1993) are generally the same as those promulgated by the EPA.

2.4.4.1 Radioactive Contaminants

The groundwater at the chemical plant area has been analyzed for gross alpha, gross beta, radium-226, radium-228, thorium-228, thorium-230, thorium-232, and total uranium. The radioactive contaminant data for the filtered and unfiltered samples are summarized in Tables 2.6 and 2.7. The sampling and analytical procedures used for both filtered and unfiltered samples were the same, except for the filtration process. The data for filtered groundwater samples represent concentrations measured from all monitoring wells, whereas the data for unfiltered samples represent concentrations measured from only selected monitoring wells. Therefore, the data are not directly comparable. For example, the maximum levels for filtered samples generally exceed the maximum levels for unfiltered samples; however, this observation is probably not indicative of a real trend but is rather an artifact of the small number of wells from which unfiltered samples were analyzed.

Data for radionuclides were compared with the EPA and Missouri MCLs, which are listed in Table 2.8. The MCLGs for the radionuclides associated with past processing at the chemical plant (i.e., uranium, radium, and thorium) are zero because they are carcinogens; however, these radionuclides occur naturally and are expected to be present at levels exceeding zero. Therefore, the MCLs were used as the basis for comparison.

The data indicate that uranium is the only radionuclide that is elevated with respect to the MCLs (Table 2.8). The proposed MCL for uranium is 20 μg/L, which corresponds to an activity of 14 pCi/L for the isotopic ratio of uranium isotopes measured in soil at the chemical plant area. (The isotopic ratio of uranium-234 to uranium-238 in groundwater at the chemical plant area ranges from 1 to 3.) Total uranium concentrations measured for all samples ranged from 0.2 to 75 pCi/L. The distribution of uranium contamination in the weathered portion of the Burlington-Keokuk Limestone is depicted in Figure 2.9, which shows the average of detected filtered concentrations at each location. All of the concentrations that exceeded the MCL were measured in the weathered portion of the aquifer. The highest concentrations of uranium were detected in the 3000-series wells, adjacent to raffinate pit 4. Uranium has also been detected above the MCL at two locations outside of the boundary of the chemical plant area (MW-4020 and MW-4005).

The uranium concentrations in the unweathered portion of the shallow aquifer are shown in Figure 2.10. The concentrations measured for all samples in the unweathered portion of the aquifer ranged from 0.2 to 13 pCi/L, with the maximum concentration measured in an unfiltered sample from MW-4022, located south of the chemical plant area.

TABLE 2.6 Summary of Filtered Groundwater Data for the Chemical Plant Area[a]

	Weathered/Unweathered Wells[b]				Unweathered Wells			
Parameter	Detection Frequency	Range[c]	Mean[c]	Upper End[c]	Detection Frequency	Range[c]	Mean[c]	Upper End[c]
Radionuclides (pCi/L)								
Gross alpha	4/25	3.0-80	22	NA	4/7	2.0-10.0	5.6	NA
Gross beta	16/25	0.01-70	19	NA	4/7	3.5-27.1	17	NA
Radium-226	28/60	0.1-4.9	0.54	NA	5/14	0.1-0.5	0.3	NA
Radium-228	21/60	0.2-5	2.0	NA	4/14	0.6-5	1.9	NA
Thorium-228	4/63	0.15-0.8	0.5	NA	2/14	0.14-0.15	0.15	NA
Thorium-230	24/65	0.07-6.6	2.0	NA	5/14	0.5-1.2	0.99	NA
Thorium-232	6/65	0.05-0.7	0.4	NA	2/14	0.2-0.5	0.4	NA
Uranium, total	378/456	0.2-75	5.5	NA	133/160	0.2-11	2.4	NA
Metals (µg/L)								
Aluminum	42/232	11-305	54	120	11/86	11-1,900	78	490
Antimony	3/151	16-60	45	66	1/59	20-57	43	65
Arsenic	8/285	1-10	2.2	3.8	14/94	2.0-4.0	2.2	3.3
Barium	283/285	13-1,400	220	620	94/94	20-2,000 (280)	146	550
Beryllium	10/146	1.0-5.0	1.1	2.1	3/59	1.0-2.0	1.0	1.3
Cadmium	6/153	2.0-11	4.6	6.8	2/59	2.0-18	4.6	8.8
Calcium	274/274	5,400-1,200,000	160,000	480,000	94/94	13,000-470,000	55,000	150,000
Chromium	25/277	2.0-130	7.6	24	21/94	2.0-140	12	51
Cobalt	13/155	2.0-50	8.5	20	0/61	2.0-13	7.0	10
Copper	5/146	1.0-25	7.7	14	0/59	1.0-10	7.3	12
Iron	137/270	2.0-22,000	220	3,900	59/94	5.0-3,100	89	740
Lead	81/238	1.0-48	3.9	15	26/86	1.0-37	3.5	13
Lithium	96/274	5.0-930	130	530	15/94	8.4-280	38	110
Magnesium	269/269	8,000-280,000	62,000	150,000	94/94	8,100-130,000	42,000	80,000
Manganese	123/274	1.0-540	22	140	68/94	2.0-430	64	250
Mercury	7/153	0.10-3.0	0.17	0.86	1/59	0.10-1.0	0.12	0.35
Molybdenum	13/151	3.0-220	32	97	9/59	3.0-71	26	57
Nickel	39/274	4.0-330	24	77	4/94	4.0-31	17	27
Potassium	222/269	700-11,000	2,600	7,100	73/94	360-72,000	7,500	39,000
Selenium	57/153	1.0-65	4.9	21	9/59	1.0-150	7.2	46
Silver	1/239	2.0-11	7.2	11	0/86	2.0-10	7.1	11
Sodium	269/269	4,900-2,000,000	73,000	420,000	94/94	3,300-210,000	21,000	74,000
Thallium	2/126	2.0-20	3.5	7.7	0/54	2.0-20	3.2	8.4
Vanadium	115/145	3.0-110	19	51	46/59	3.0-49	14	32
Zinc	103/146	3.0-160	19	64	40/59	3.0-87	19	55

TABLE 2.6 (Cont.)

Parameter	Weathered/Unweathered Wells[b] Detection Frequency	Range[c]	Mean[c]	Upper End[c]	Unweathered Wells Detection Frequency	Range[c]	Mean[c]	Upper End[c]
Inorganic anions (mg/L)								
Chloride	307/313	0.25-350	18	100	118/122	0.50-10	2.5	6.2
Fluoride	26/52	0.050-1.2	0.34	0.78	21/29	0.13-0.45	0.29	0.52
Nitrate (as N)	427/465	0.02-12,000 (3,500)	150	1,400	76/164	0.02-1,200	16	250
Sulfate	462/465	1.2-1,000	79	350	162/162	1.6-9,100 (640)	90	1,500
Nitroaromatic compounds (µg/L)								
1,3-DNB	13/448	0.09-0.22	0.15	NA	0/137	ND[d]	ND	NA
2,4-DNT	239/447	0.03-8.5	0.53	NA	3/137	0.06-0.12	0.09	NA
2,6-DNT	260/450	0.01-30	1.9	NA	3/137	0.05-0.33	0.16	NA
NB	21/459	0.03-0.08	0.05	NA	1/137	0.03	0.03	NA
1,3,5-TNB	193/447	0.03-66	8.8	NA	1/137	0.05	0.05	NA
2,4,6-TNT	96/447	0.03-31	2.3	NA	1/137	2.2	2.2	NA

[a] Summary includes data collected from June 1990 to December 1993.

[b] Includes wells open only to the weathered unit and wells open to both the weathered and unweathered units of the Burlington-Keokuk.

[c] For radionuclides and nitroaromatic compounds, the range and mean of concentrations at or above the detection limit are given; NA indicates that no upper-end values are given because these values are not compared with background values. For metals and inorganic anions, to facilitate comparison with background levels, the range, mean, and upper-end values given assume concentrations equal to the sample detection limit for values reported as not detected. Upper-end values are equal to the mean plus two standard deviations. Values are rounded to two significant figures. A value in parentheses is the second highest value indicated for the range; the highest values in these cases are suspected outliers.

[d] ND indicates not detected.

TABLE 2.7 Summary of Unfiltered Groundwater Data for the Chemical Plant Area[a]

	Weathered/Unweathered Wells[b]				Unweathered Wells			
Parameter	Detection Frequency	Range[c]	Mean[c]	Upper End[c]	Detection Frequency	Range[c]	Mean[c]	Upper End[c]
Radionuclides (pCi/L)								
Gross alpha	0/2	ND[d]	ND	NA	0/1	ND	ND	NA
Gross beta	1/2	17	17	NA	0/1	ND	ND	NA
Radium-226	5/5	0.1-1.2	0.74	NA	7/9	0.05-3.4	0.9	NA
Radium-228	5/5	0.3-1.8	0.84	NA	1/9	0.2	0.2	NA
Thorium-228	1/5	0.7	0.7	NA	6/9	0.1-0.8	0.3	NA
Thorium-230	3/5	0.1-0.9	0.4	NA	8/9	0.5-3.4	1.4	NA
Thorium-232	2/5	0.1-0.2	0.15	NA	7/9	0.2-1.2	0.6	NA
Uranium, total	13/14	1-18	9.4	NA	11/18	0.2-13	3.3	NA
Metals (µg/L)								
Aluminum	12/12	35-13,000	2,300	9,800	4/5	35-26,000	7,100	30,000
Arsenic	2/11	2.0-3.0	2.2	3.0	3/5	1.0-4.0	2.2	4.4
Barium	11/11	87-680	250	580	5/5	76-340	194	440
Calcium	12/12	59,000-370,000	190,000	400,000	5/5	29,000-98,000	77,000	140,000
Chromium	4/12	6.0-61	14	45	2/5	6.0-88	37	120
Iron	12/12	41-23,000	5,000	19,000	4/5	19-42,000	12,000	50,000
Lead	10/12	2-200	34	140	3/5	2.0-200	53	200
Lithium	4/12	23-900	220	870	1/5	24-100	56	140
Magnesium	12/12	19,000-150,000	52,000	130,000	5/5	21,000-60,000	45,000	74,000
Manganese	12/12	7.0-1,100	300	1,000	5/5	47-1,500	570	1,900
Nickel	5/12	11-100	27	77	2/5	11-150	61	190
Potassium	12/12	1,400-10,000	3,900	8,300	5/5	12-10,000	3,400	9,800
Silver	0/12	6.0-10	7.8	11	1/5	4.0-10	7.0	12
Sodium	12/12	8,800-220,000	86,000	240,000	5/5	12,000-29,000	19,000	33,000
Inorganic anions (mg/L)								
Chloride	12/12	1.6-40	15	38	5/5	0.77-5.3	2.6	6.6
Nitrate (as N)	13/14	0.13-340	84	350	11/18	0.070 -0.5	0.19	0.47
Sulfate	14/14	5.6-650	171	630	18/18	7.4-130	26	79

TABLE 2.7 (Cont.)

Parameter	Weathered/Unweathered Wells[b]				Unweathered Wells			
	Detection Frequency	Range[c]	Mean[c]	Upper End[c]	Detection Frequency	Range[c]	Mean[c]	Upper End[c]
Nitroaromatic compounds (µg/L)								
1,3-DNB	0/14	ND	ND	NA	0/18	ND	ND	NA
2,4-DNT	9/14	0.06-8	1.9	NA	0/18	ND	ND	NA
2,6-DNT	9/14	0.13-11	6.8	NA	0/18	ND	ND	NA
NB	0/14	ND	ND	NA	0/18	ND	ND	NA
1,3,5-TNB	6/14	0.03-4.2	1.3	NA	0/18	ND	ND	NA
2,4,6-TNT	7/14	0.03-8.1	2.3	NA	0/18	ND	ND	NA

[a] Summary includes data collected from June 1990 to December 1993.

[b] Includes wells open only to the weathered unit and wells open to both the weathered and unweathered units of the Burlington-Keokuk.

[c] For radionuclides and nitroaromatic compounds, the range and mean of concentrations at or above the detection limit are given; NA indicates that no upper-end values are given because these values are not compared with background values. For metals and inorganic anions, to facilitate comparison with background levels, the range, mean, and upper-end values given assume concentrations equal to the sample detection limit for values reported as not detected. Upper-end values are equal to the mean plus two standard deviations. Values are rounded to two significant figures.

[d] ND indicates not detected.

TABLE 2.8 Comparison of Groundwater Contaminant Concentrations at the Chemical Plant Area with Regulatory Standards[a]

Contaminant	Maximum Detected Concentration in Groundwater (6/90-12/93 Data)		EPA Drinking Water Regulations			Missouri Safe Drinking Water Act	
	Filtered	Unfiltered	MCL	MCLG	SMCL	MCL	SMCL
Radionuclides (pCi/L)							
Radium-226	4.9	3.4	20[b]	0	-	5[c]	-
Radium-228	5.0	1.8	20[b]	0	-	5[c]	-
Uranium, total	75	18	30[d]	0	-	-	-
Metals (µg/L)							
Aluminum	1,870	26,000	-	-	50-200	-	50-200
Antimony	53	NA	6	6	-	6	-
Arsenic	8.0	4.0	50[e]	-	-	50	-
Barium	2,000	660	2,000	2,000	-	2,000	-
Beryllium	3.0	NA	4	4	-	4	-
Cadmium	18	NA	5	5	-	5	-
Chromium (total)	139	68	100	100	-	100	-
Copper	15	NA	-	1,300[f]	1,000	1,300[f]	1,000
Iron	21,700	42,400	-	-	300	-	300
Lead	48	200	15[f]	0	-	15[f]	-
Manganese	538	1,540	-	-	50	-	50
Mercury	3.0	NA	2	2	-	2	-
Nickel	327	151	100	100	-	100	-
Selenium	65	NA	50	50	-	50	-
Silver	11	9	-	-	100	-	100
Thallium	2.0	NA	2	0.5	-	2	-
Zinc	162	NA	-	-	5,000	-	5,000
Inorganic anions (mg/L)							
Chloride	350	39.5	-	-	250	-	250
Fluoride	1.2	NA	4[e]	4[e]	2[e]	4.0	2
Nitrate (as N)	3,530	338	10	10	-	10	-
Sulfate	1,030	650	500	500	250	-	250

Contaminant	Maximum Detected Concentration in Groundwater (6/90-12/93 Data)		Health Advisory Levels[g]
	Filtered	Unfiltered	
Nitroaromatic compounds (µg/L)			
1,3-DNB	0.22	ND	1
2,4-DNT	8.5	8	0.05
2,6-DNT	30	11	0.05
2,4,6-TNT	31	8.1	1

[a] Notation: NA = not available; ND = not detected; MCL = maximum contaminant level; MCLG = maximum contaminant level goal; and SMCL = secondary maximum contaminant level. A hyphen indicates that no standard exists for that parameter.

[b] Proposed value.

[c] Concentration of radium-226 and radium-228 combined.

[d] The MCL is 20 µg/L, which corresponds to 30 pCi/L, for a uranium-234 to uranium-238 activity ratio of 2.7, as reported by the EPA. For an activity concentration ratio of uranium isotopes found in soil at the Weldon Spring site, the corresponding MCL is 14 pCi/L.

[e] Under review.

[f] Treatment technology action level.

[g] Health advisory levels are nonenforceable health-risk-based guidelines derived by the EPA (1995). The reference document provides health advisory levels for carcinogens equivalent to a 10^{-4} risk level; these levels have been converted to a 10^{-6} risk level for use in this table.

Sources: EPA (1995); Missouri Department of Natural Resources (1993).

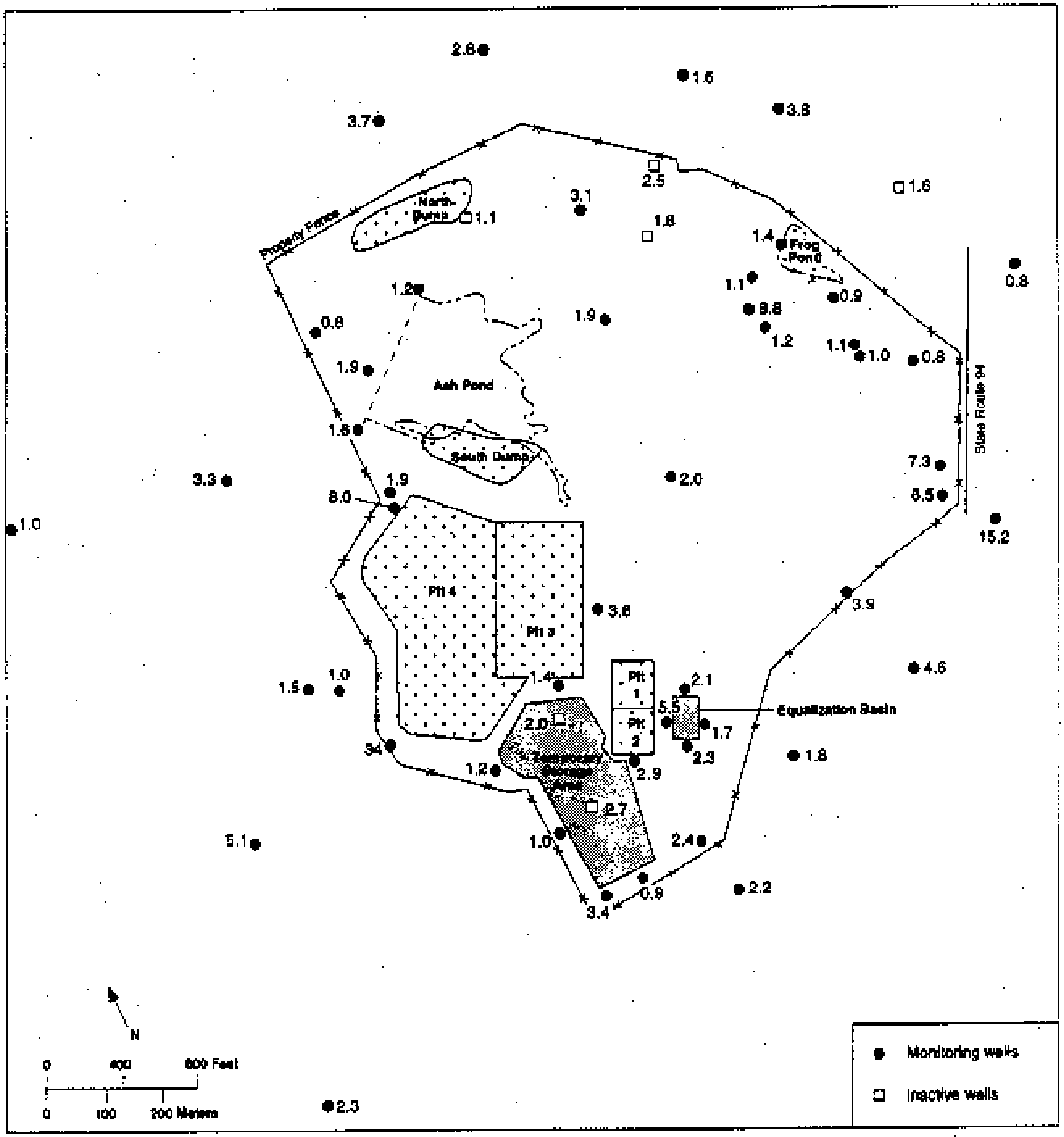


FIGURE 2.9 Average Detected Concentrations of Uranium (pCi/L) in the Weathered Burlington-Keokuk Limestone

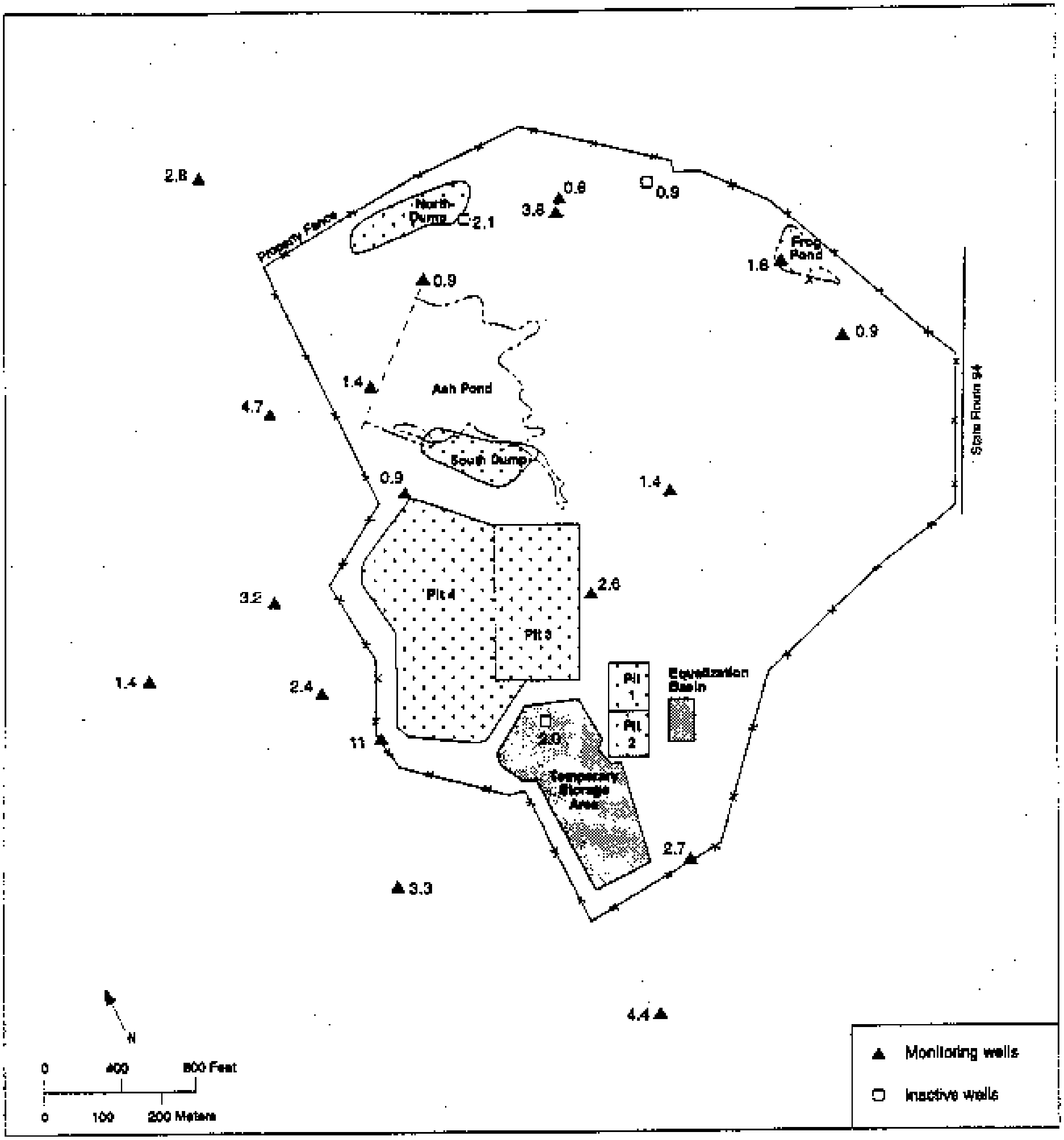


FIGURE 2.10 Average Detected Concentrations of Uranium (pCi/L) in the Unweathered Burlington-Keokuk Limestone

Radium and thorium were detected in a number of the groundwater samples at low concentrations. Detected concentrations of radium-226 and radium-228 for each well were below the proposed EPA MCL of 20 pCi/L and were also below the more restrictive Missouri MCL of 5 pCi/L for combined radium. Concentrations of thorium-228, thorium-230, and thorium-232 were below the EPA and Missouri MCL of 15 pCi/L for adjusted gross alpha. These radionuclides were eliminated from further consideration for the chemical plant area (Table 2.8).

2.4.4.2 Chemical Contaminants

The horizontal and vertical extent of chemical contamination in the shallow groundwater system was analyzed in a manner similar to that used in the assessment of radioactive contamination. The metals, inorganic anions, and nitroaromatic compounds detected in groundwater at the chemical plant area are summarized in Tables 2.6 and 2.7 for filtered and unfiltered samples, respectively. The data for filtered and unfiltered samples are not directly comparable because relatively few unfiltered samples were analyzed (see Section 2.4.4.1).

Metals. Monitoring for various metals in groundwater is ongoing at the chemical plant area, although monitoring frequency is less than that performed for nitroaromatics, nitrates, and uranium. For most of the metals analyzed, the highest concentrations in groundwater were generally measured in samples collected from the weathered rather than from the unweathered zone of the Burlington-Keokuk Limestone.

As a preliminary indicator of elevated metal concentrations in groundwater, the concentrations of metals in monitoring wells in the chemical plant area (Tables 2.6 and 2.7) were compared with the background concentrations (Tables 2.3 and 2.4). Specifically, the upper end of the range of concentrations in the chemical plant area (i.e., mean plus two standard deviations) was compared to the upper end of the range of background concentrations. Values from the chemical plant area that are more than twice the background values may be considered indicative of elevated groundwater concentrations for specific metals, although the results of the joint sampling effort will be used to further examine these data in the RI. For the upper-end values from the chemical plant area that were between one and two times the background upper-end value, the results are considered uncertain because the statistical significance of the difference is questionable.

Levels of aluminum, barium, chromium, iron, lead, magnesium, manganese, nickel, potassium, selenium, sodium, thallium, and vanadium were elevated above background concentrations in at least one well group. The trend is consistent for levels of chromium and sodium, which were elevated in filtered and unfiltered samples collected from wells open to the weathered and unweathered units. Levels of calcium were slightly higher in wells of the chemical plant area than in background wells for all groups, but the increase was never greater than two times the background value. The level of lead was elevated only in unfiltered samples. Elevated levels of aluminum were only detected in unfiltered samples from unweathered wells, but this finding is of questionable significance because the data represent only five samples from the chemical plant area.

The groundwater data from the chemical plant area were also compared with EPA criteria (i.e., MCLs, SMCLs, or MCLGs) to determine if levels in any individual monitoring well exceeded these criteria. The metals listed in Table 2.9 are those that did not exceed the criteria in any wells or exceeded the criteria only once in wells for which the number of samples was sufficient to confirm that the exceedance was nonrepresentative. The metals listed in Table 2.9 are highly unlikely to represent a human health risk in groundwater from the chemical plant area, regardless of whether or not they exceed background concentrations.

In some cases, the lowest detection limit exceeded the regulatory standard; for example, the lowest detection limit for antimony (16 µg/L) is higher than the regulatory standard (6 µg/L). This problem also existed for some of the thallium data. Lower detection limits will be required for these metals in forthcoming analytical rounds.

Metals that had concentrations above the drinking water standards but were infrequently detected include antimony, cadmium, mercury, and thallium. The detection limit problem notwithstanding, antimony was detected six times in 214 samples at levels exceeding the MCL of 6 µg/L, with a maximum concentration of 53 µg/L. The maximum concentration of cadmium was 18 µg/L, with a detection frequency of only eight of 216. Mercury was detected in about 4% of the samples; the maximum concentration was 3.0 µg/L, with two samples exceeding the MCL and MCLG of 2 µg/L. Thallium was found in only two of 185 samples (at 2.0 µg/L); however, the detection limits ranged from 2 to 20 µg/L, whereas the MCL is 2 µg/L.

Lead, nickel, and selenium were detected relatively frequently and at maximum levels that exceeded EPA drinking water criteria. Lead was detected in approximately one-third of the samples. The maximum value for lead, 200 µg/L, was detected in an unfiltered sample collected from the off-site unweathered MW-4022; lead concentrations in filtered samples were considerably lower, with nine detected levels exceeding the EPA technology-based action level for lead of 15 µg/L. The frequency of detection for nickel was 51 of 390 samples; the maximum value of 327 µg/L, which exceeds the MCL and MCLG of 100 µg/L, was detected in the weathered well MW-3023 (northern edge of raffinate pit 4). Selenium was detected in a number of samples. The maximum value of 65 µg/L, which exceeds the MCL and MCLG of 50 µg/L, was detected in MW-2041 near the equalization basin of the site water treatment plant. Chromium was also detected at levels greater than the MCL of 100 µg/L in two of 392 samples, with a maximum concentration of 139 µg/L in well MW-4012; however, concentrations of chromium in all other samples from these wells were less than the MCL.

Aluminum, iron, and manganese were detected relatively frequently. In preliminary comparisons with background levels, the concentration of iron appears to be elevated,

TABLE 2.9 Constituents at the Chemical Plant Area that Do Not Exceed EPA Criteria

Substance	Rationale
Radium-226	Maximum concentration was 4.9 pCi/L; proposed MCL is 20 pCi/L.
Radium-228	Maximum concentration was 5.0 pCi/L; proposed MCL is 20 pCi/L.
Thorium-228	Maximum concentration was 0.8 pCi/L; proposed MCL for adjusted gross alpha is 15 pCi/L.
Thorium-230	Maximum concentration was 6.6 pCi/L; proposed MCL for adjusted gross alpha is 15 pCi/L.
Thorium-232	Maximum concentration was 1.2 pCi/L; proposed MCL for adjusted gross alpha is 15 pCi/L.
Arsenic	Maximum concentration was 8 µg/L; MCL is 50 µg/L; detection frequency 7%.
Barium	A single sample from well MW-3026 (a retrofitted well for MW-3009 southwest of the raffinate pits) had a concentration equal to the MCL of 2,000 µg/L. Eleven samples from MW-3009 were all less than the MCL, with an average concentration of 1,207 µg/L. All other samples had concentrations less than the MCL.
Beryllium	Maximum concentration was 3 µg/L; MCL is 4 µg/L; detection frequency 5%.
Copper	Maximum concentration was 15 µg/L; MCL is 1,300 µg/L; detection frequency 3%.
Fluoride	Maximum concentration was 1.2 mg/L; MCL is 4 mg/L; detection frequency 58%.
Silver	Maximum concentration was 11 µg/L; SMCL is 100 µg/L; detection frequency 0.5%.
Zinc	Maximum concentration was 162 µg/L; MCL is 5,000 µg/L; detection frequency 71%.

whereas the results for aluminum and manganese are uncertain. All three metals exceeded SMCLs in several samples. The SMCLs are based on aesthetic considerations (e.g., taste and odor), rather than on human health effects. The maximum detected concentration of aluminum was 26,000 µg/L in an unfiltered sample from MW-4022, a well open to the unweathered portion of the Burlington-Keokuk south of the site. The SMCL range for aluminum is 50 to 200 µg/L. Fifteen of 17 unfiltered samples had aluminum concentrations exceeding 200 µg/L, whereas only two of 236 filtered samples exceeded 200 µg/L. Iron was detected in over half of the samples. The maximum iron concentration, 42,400 µg/L, was detected in an unfiltered sample. Twelve of 18 unfiltered samples had iron concentrations greater than the SMCL of 300 µg/L; only six of 273 filtered samples exceeded the SMCL. Manganese was also detected in more than half of the samples. The maximum concentration of manganese was 1,540 µg/L, which was detected in an unfiltered sample from MW-4022. Twelve of 17 unfiltered and 51 of 278 filtered samples exceeded the SMCL of 50 µg/L for manganese.

Inorganic Anions. Background data for inorganic anions were not available for filtered samples, so comparisons with background are inconclusive for chemical plant data, which primarily consist of filtered samples. On the basis of the limited data on unfiltered samples, nitrate appears to be elevated at the chemical plant area in both weathered and unweathered well groups. Chloride and sulfate levels also appear to be elevated in wells open to the weathered unit.

Similar to metals, the higher concentrations of nitrate were detected in the weathered zone, often at values exceeding the MCL of 10 mg/L. Except for a few suspected outliers, all detected concentrations in the unweathered unit of the Burlington-Keokuk are below the MCL. Nitrate contamination at concentrations greater than 10 mg/L is widespread in the weathered unit of the shallow aquifer; however, the highest levels are generally concentrated in localized areas. Several monitoring wells in the Ash Pond area (MW-2001, MW-2002, MW-2003, and MW-2005) had maximum nitrate concentrations ranging from 97 to 785 mg/L. Maximum nitrate levels up to 3,530 mg/L were detected in the wells surrounding the raffinate pits, reflecting a major source of nitrates. Off-site monitoring locations with elevated nitrate concentrations include MW-4001, which is directly west of the raffinate pits (maximum of 43 mg/L), and MW-4018, located to the east of Frog Pond (maximum of 11 mg/L).

The detected concentrations of the remaining inorganic anions — chloride, fluoride, and sulfate — appear to be less significant than nitrate concentrations; however, at several locations, the maximum concentrations of sulfate exceeded the SMCL of 250 mg/L and the MCL of 500 mg/L. These elevated sulfate concentrations were detected primarily near the raffinate pits and in the northeastern portion of the site. With the exclusion of a suspected outlier, the maximum sulfate concentration of 1,030 mg/L was measured near the raffinate pits.

As with sulfate, most of the samples analyzed contained detectable levels of chloride; however, only one location had concentrations greater than the SMCL of 250 mg/L (maximum of 350 mg/L at MW-2006, near the northeastern site boundary). The maximum fluoride concentration measured was 1.2 mg/L, which is less than the MCL and MCLG of 4 mg/L and the SMCL of 2 mg/L.

Nitroaromatic Compounds. Samples collected from the monitoring wells were analyzed for six nitroaromatic compounds: 2,4-dinitrotoluene (2,4-DNT); 2,6-DNT; 2,4,6-trinitrotoluene (2,4,6-TNT); 1,3,5-trinitrobenzene (1,3,5-TNB); 1,3-dinitrobenzene (1,3-DNB); and nitrobenzene (NB). The compounds 2,4-DNT; 2,6-DNT; 1,3,5-TNB; and 2,4,6-TNT were generally detected at greater frequency and concentrations than 1,3-DNB and NB. Most nitroaromatic compounds were detected within the weathered unit of the

Burlington-Keokuk Limestone. Although the maximum concentrations of each nitroaromatic compound varied with location, the highest levels of nitroaromatics were typically found in the northeastern portion of the chemical plant area near Frog Pond and in the southwestern portion in the vicinity of the raffinate pits. These two areas have both elevated levels of several nitroaromatics and increased frequencies of detection. Several of the 4000-series monitoring wells have elevated levels of nitroaromatics, especially directly west of the raffinate pits. Elevated concentrations of 2,4,6-TNT (31 µg/L); 2,4-DNT (7.4 µg/L); 2,6-DNT (6.8 µg/L); and 1,3,5-TNB (75 µg/L) have been detected off-site, adjacent to the western boundary and near the raffinate pits (MW-4001). The highest concentration of 1,3,5-TNB was detected at an off-site location: 86 µg/L just north of the chemical plant area (MW-4013).

The highest concentrations of 2,4-DNT (8.5 and 7.4 µg/L) were detected near the raffinate pits in wells MW-3023 and MW-4001, respectively. The next highest level of 2,4-DNT (3.8 µg/L) — and the maximum concentration of 2,6-DNT (30 µg/L) — were measured in the northeastern portion of the chemical plant area near Frog Pond (MW-2033 and MW-2030, respectively). The second and third highest concentrations of 2,4,6-TNT (14 and 9.0 µg/L) were also detected in the northern and northeastern parts of the chemical plant.

The measured concentrations of nitroaromatics have not been compared with groundwater standards because no standards are available for these compounds. Health advisory levels derived by the EPA (1995) are available for four nitroaromatic compounds: 1,3-DNB; 2,4-DNT; 2,6-DNT; and 2,4,6-TNT. Of these nitroaromatic compounds, the maximum detected concentrations of 2,4-DNT; 2,6-DNT; and 2,4,6-TNT at the chemical plant area exceed the health advisory level (EPA 1995). The average detected concentrations of 1,3-DNB; 2,4-DNT; 2,6-DNT; and 2,4,6-TNT are shown in Figures 2.11 through 2.14, respectively.

Organic Contaminants. Groundwater at the chemical plant area has been tested for the Contract Laboratory Program (CLP) Target Compound List, including PCBs and pesticides. In one round of sampling of 29 monitoring wells conducted in 1987 (DOE 1987), none of these compounds were detected.

2.4.5 Groundwater at the Ordnance Works Area

Similar to the groundwater summaries presented for the chemical plant area, the groundwater data for the ordnance works area have been summarized by separating the data into groups on the basis of the well completions to assist in understanding the vertical distribution of contamination (Mugel 1994a). This summary focuses on the data collected from two major stratigraphic units defined within the Burlington-Keokuk Limestone. The first data set includes groundwater concentrations obtained from wells open only to the weathered zone and wells open across both the weathered and unweathered units of the

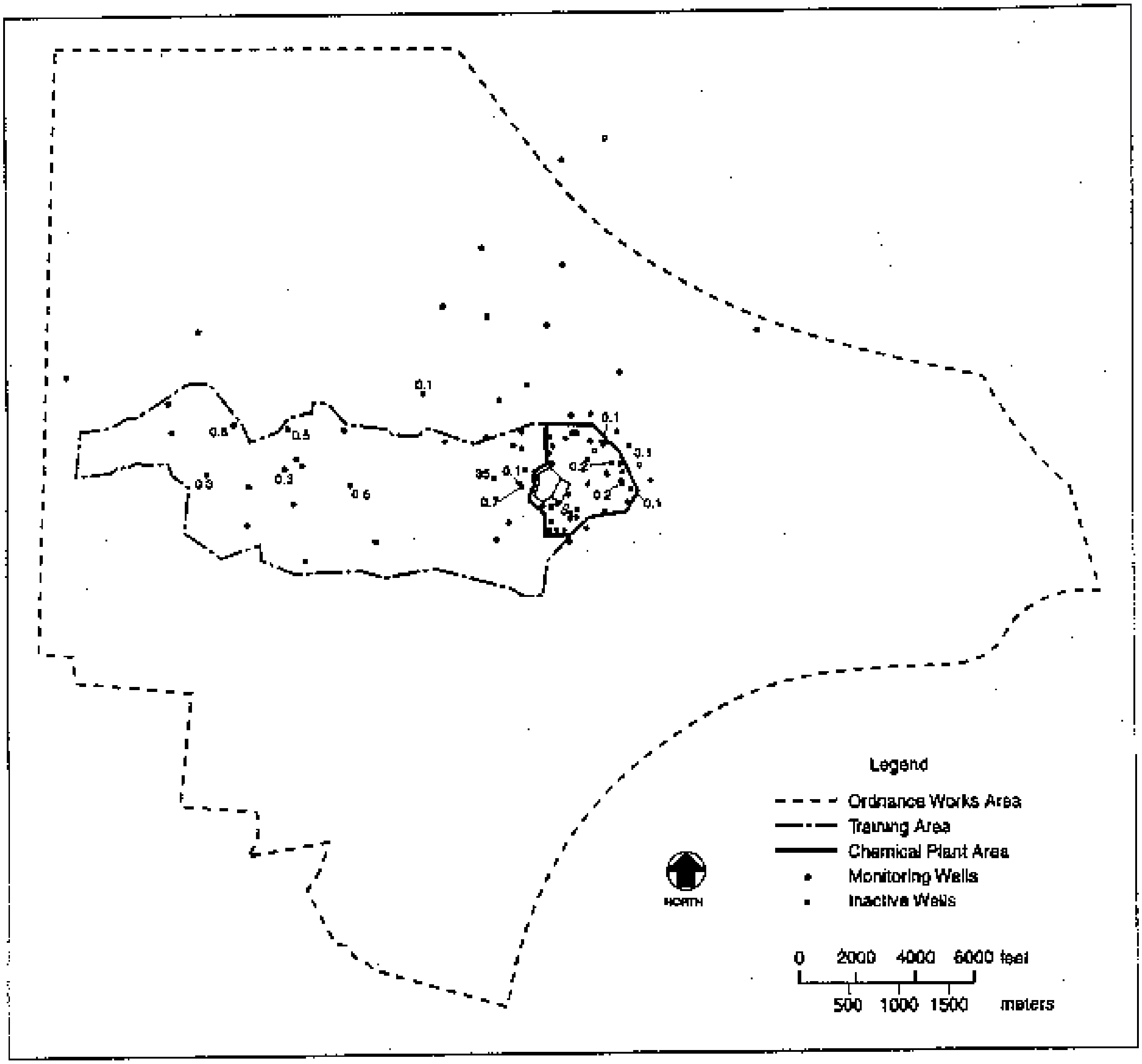


FIGURE 2.11 Average Detected Concentrations of 1,3-Dinitrobenzene (µg/L) in the Weathered Unit of the Burlington-Keokuk Limestone

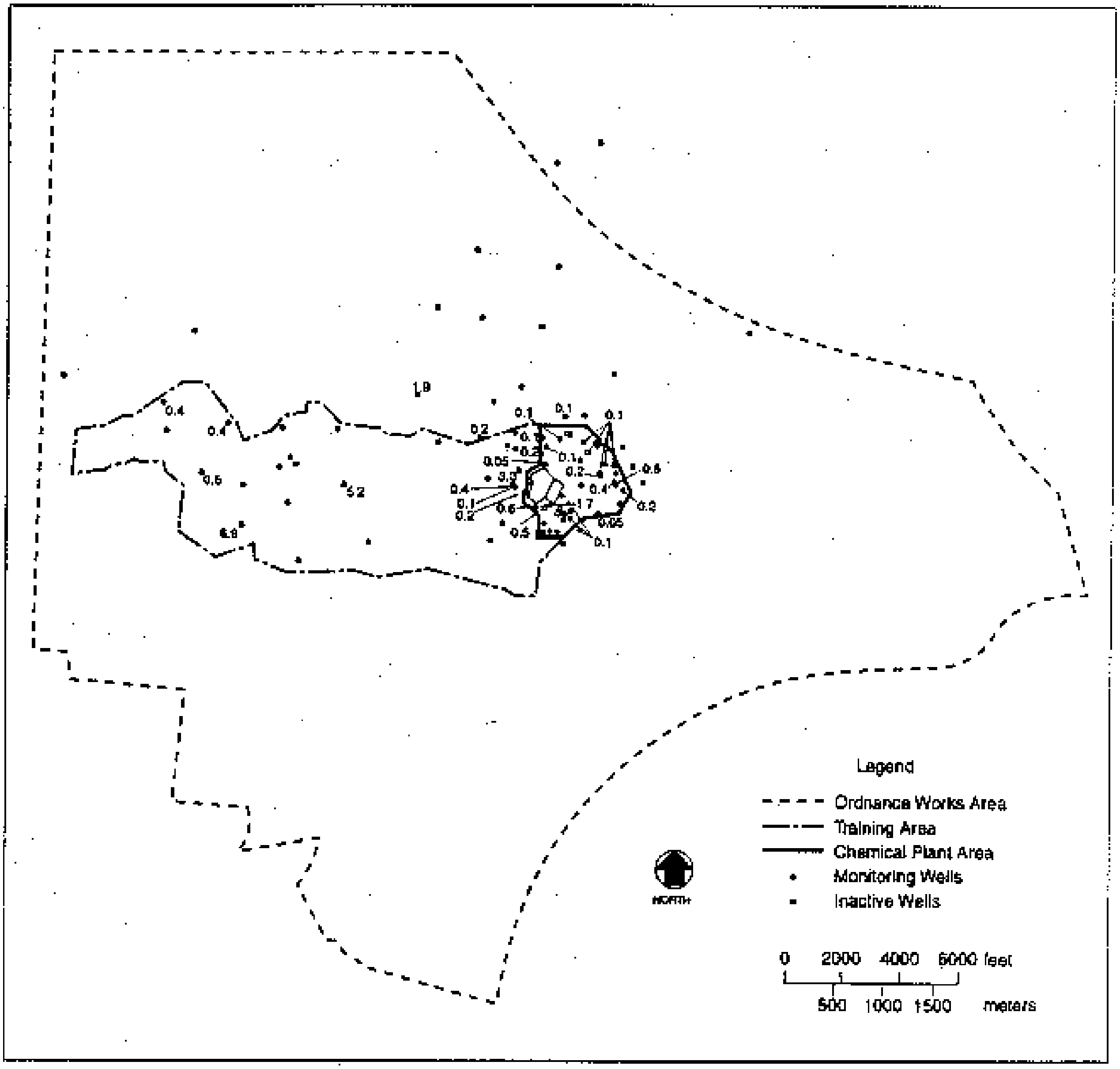


FIGURE 2.12 Average Detected Concentrations of 2,4-Dinitrotoluene (μg/L) in the Weathered Unit of the Burlington-Keokuk Limestone

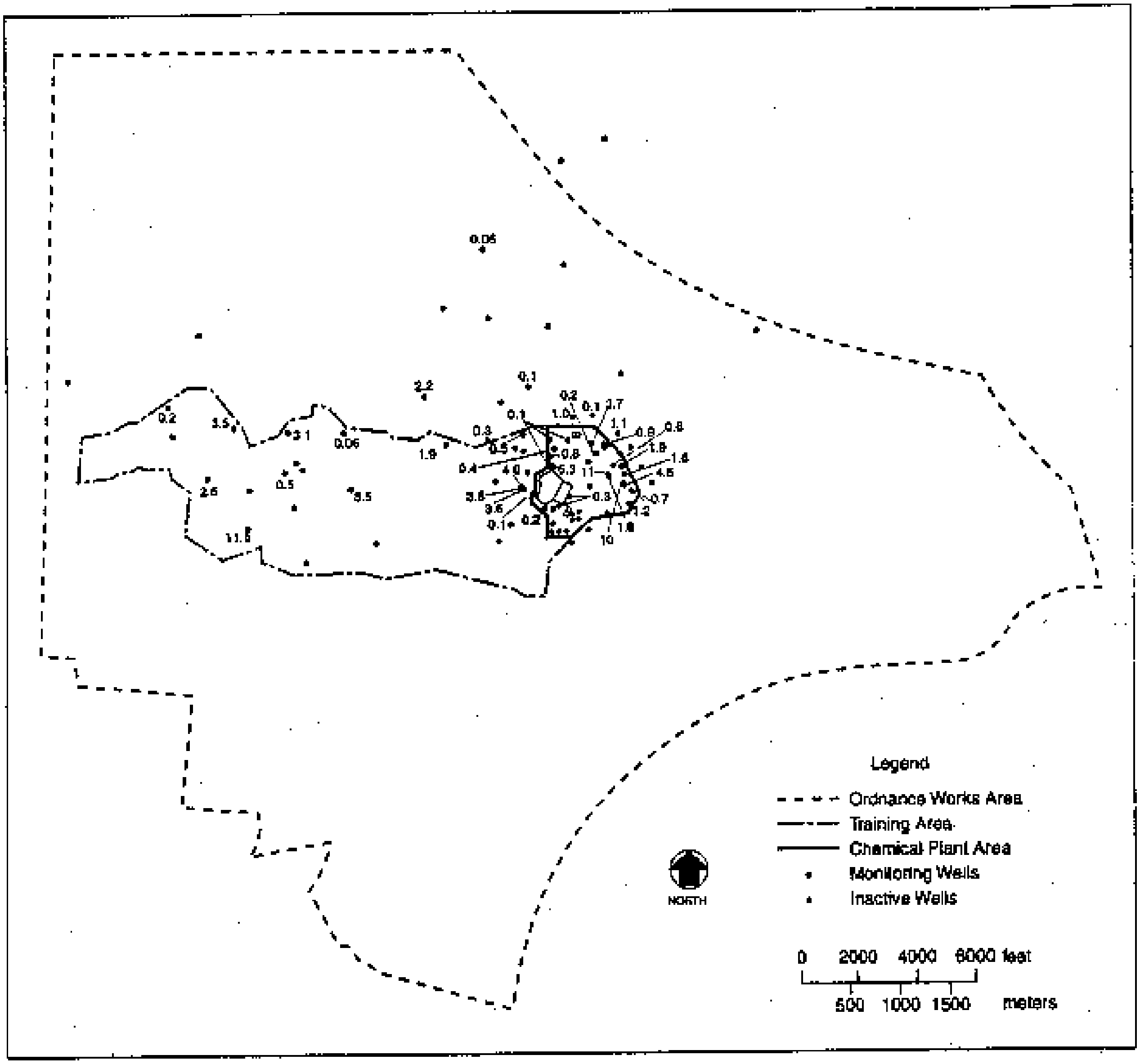


FIGURE 2.13 Average Detected Concentrations of 2,6-Dinitrotoluene (µg/L) in the Weathered Unit of the Burlington-Keokuk Limestone

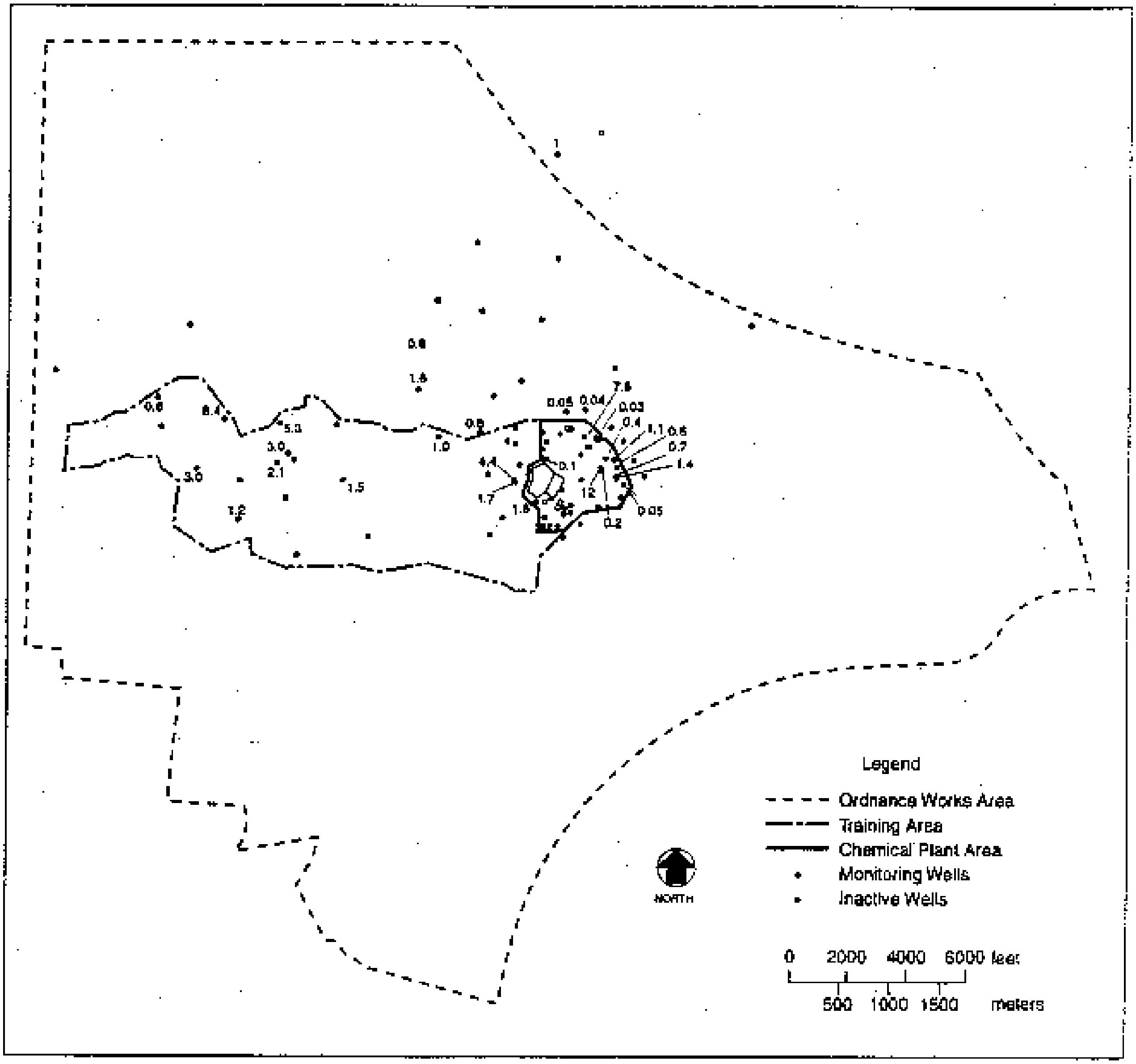


FIGURE 2.14 Average Detected Concentrations of 2,4,6-Trinitrotoluene (µg/L) in the Weathered Unit of the Burlington-Keokuk Limestone

Burlington-Keokuk Limestone; the second data set consists of groundwater data collected from wells open only to the unweathered zone. Four wells open partially to the unweathered unit and the Fern Glen Formation were included with the second data set. Data from additional well groups (i.e., wells open to the deeper formations, wells open to the vadose zone, and USGS wells to the north of the training area) are summarized separately. The wells were assigned identification labels according to completion depth and spatial location. The "V" series wells (MWV) are completed in the vadose zone (i.e., overburden); the "S" series wells (MWS) are generally shallow; and the "D" series wells (MWD) are deeper. These designations were assigned prior to comparing the screened interval to the stratigraphic units (e.g., weathered or unweathered units of the Burlington-Keokuk Limestone and Fern Glen Formation); consequently, a well identification number that includes a "D" does not always mean that the well is completed in the unweathered portion of the Burlington-Keokuk Limestone. At the ordnance works area, wells numbered 1 to 24 are located within the training area; and wells numbered 101 to 111, USGS, and MWGS are located outside of the training area boundary. The monitoring wells are listed in Table 2.10, and the locations are shown in Figures 2.7 and 2.15.

Most of the monitoring wells were installed as part of the work performed for the two remedial investigations at the ordnance works area (IT Corporation 1992a, 1993a). Details of well construction and development of the wells installed by IT Corporation are contained in the final RI report for the training area (IT Corporation 1993a). In addition to IT-installed wells, the groundwater data from the ordnance works area include samples from 12 USGS wells, one Army well at the training area, and two wells formerly used as domestic supplies (i.e., TIL 3 and TIL 4).

The assessment of groundwater quality in the Army areas is based on data obtained between March 1989 and May 1994, a period of time comparable to that of the data for the chemical plant area. Parameters include radioactive contaminants (gross alpha and gross beta), nitroaromatic compounds (from 6 to 11 compounds), 23 metals (filtered and unfiltered samples analyzed), and inorganic anions; the data are presented in Tables 2.11 and 2.12. The concentrations of chemical constituents are compared with background concentrations (Tables 2.3 and 2.4) and with criteria established by the EPA (1995) for public drinking water supplies, as discussed in Section 2.4.2. Criteria established by the state of Missouri under the Missouri Safe Drinking Water Act (Missouri Department of Natural Resources 1993) are generally the same as those promulgated by the EPA.

2.4.5.1 Radioactive Contaminants

At the ordnance works area, only one round of sampling has been completed for radionuclides because, historically, radioactive materials were not processed at the training area. Unfiltered samples were analyzed for gross alpha and gross beta; these data are presented in Table 2.12. As a general means of interpretation, the gross alpha data were compared to EPA's proposed MCL of 15 pCi/L for adjusted gross alpha; however, this

TABLE 2.10 Monitoring Wells at the Ordnance Works Area

Location/ Well Number	Completion Interval	Location/ Well Number	Completion Interval
Training Area		Ordnance Works Area	
MWV 1	Vadose (overburden)	MWS 101	Kimmswick
MWS 1	Weathered/unweathered	MWS 102	Decorah
MWV 2	Vadose (overburden)	MWS 103	Sulphur Springs/Kimmswick
MWS 2[a]	Weathered/unweathered	MWS 104	Weathered/unweathered
MWD 2	Unweathered	MWS 105	Unweathered
MWS 3[b]	Weathered/unweathered	MWD 105	Unweathered/Fern Glen
MWS 4	Weathered	MWS 106	Unweathered
MWS 5	Unweathered/Fern Glen	MWD 106	Unweathered/Fern Glen
MWD 5[c]	Fern Glen/Chouteau	MWS 107	Weathered/unweathered
MWS 6	Unweathered	MWS 108	Unweathered
MWD 6	Unweathered	MWS 109	Unweathered
MWS 7	Weathered	MWD 109	Unweathered/Fern Glen
MWV 8	Vadose (overburden)	MWS 110	Weathered/unweathered
MWS 8	Weathered	MWS 111	Weathered
MWV 9	Vadose (overburden)	USGS 1[d]	Burlington-Keokuk
MWS 9	Weathered	USGS 2	Burlington-Keokuk
MWD 9	Unweathered	USGS 2A	Overburden/Burlington-Keokuk
MWS 10	Weathered	USGS 3	Burlington-Keokuk
MWS 11	Weathered	USGS 4	Burlington-Keokuk
MWS 12	Weathered	USGS 5	?/Burlington-Keokuk
MWV 13	Vadose (overburden)	USGS 6	Burlington-Keokuk
MWS 13	Weathered	USGS 7[d]	Burlington-Keokuk/?
MWS 14	Weathered	USGS 8	Burlington-Keokuk
MWS 15	Weathered	USGS 9	Burlington-Keokuk
MWD 15	Weathered	MWGS 1[e]	?/Kimmswick
MWV 16	Vadose (overburden)	MWGS 2[e]	Joachim/St. Peter
MWS 16	Weathered	TIL 3[f]	Unknown
MWV 17	Vadose (overburden)	TIL 4[f]	Burlington-Keokuk/Fern Glen
MWS 17[b]	Weathered/unweathered	Army well	?/Sulphur Springs Group/?
MWV 18	Vadose (overburden)		
MWS 18	Chouteau/Bachelor/Sulphur Springs		
MWD 18	Kimmswick		
MWS 19	Weathered		
MWS 20	Weathered/unweathered		
MWS 21	Weathered		
MWV 22	Vadose (overburden)		
MWS 22	Weathered		
MWS 23	Weathered		
MWV 24R	Vadose (overburden)		
MWS 24[e]	Weathered		

[a] Primarily completed in the weathered unit.

[b] Primarily completed in the unweathered unit.

[c] Primarily completed in the Fern Glen.

[d] Estimated to be completed in the unweathered unit.

[e] Inactive monitoring well.

[f] Wells formerly used as domestic supplies that are now included in the CE monitoring network.

Source: Mugel (1994a).

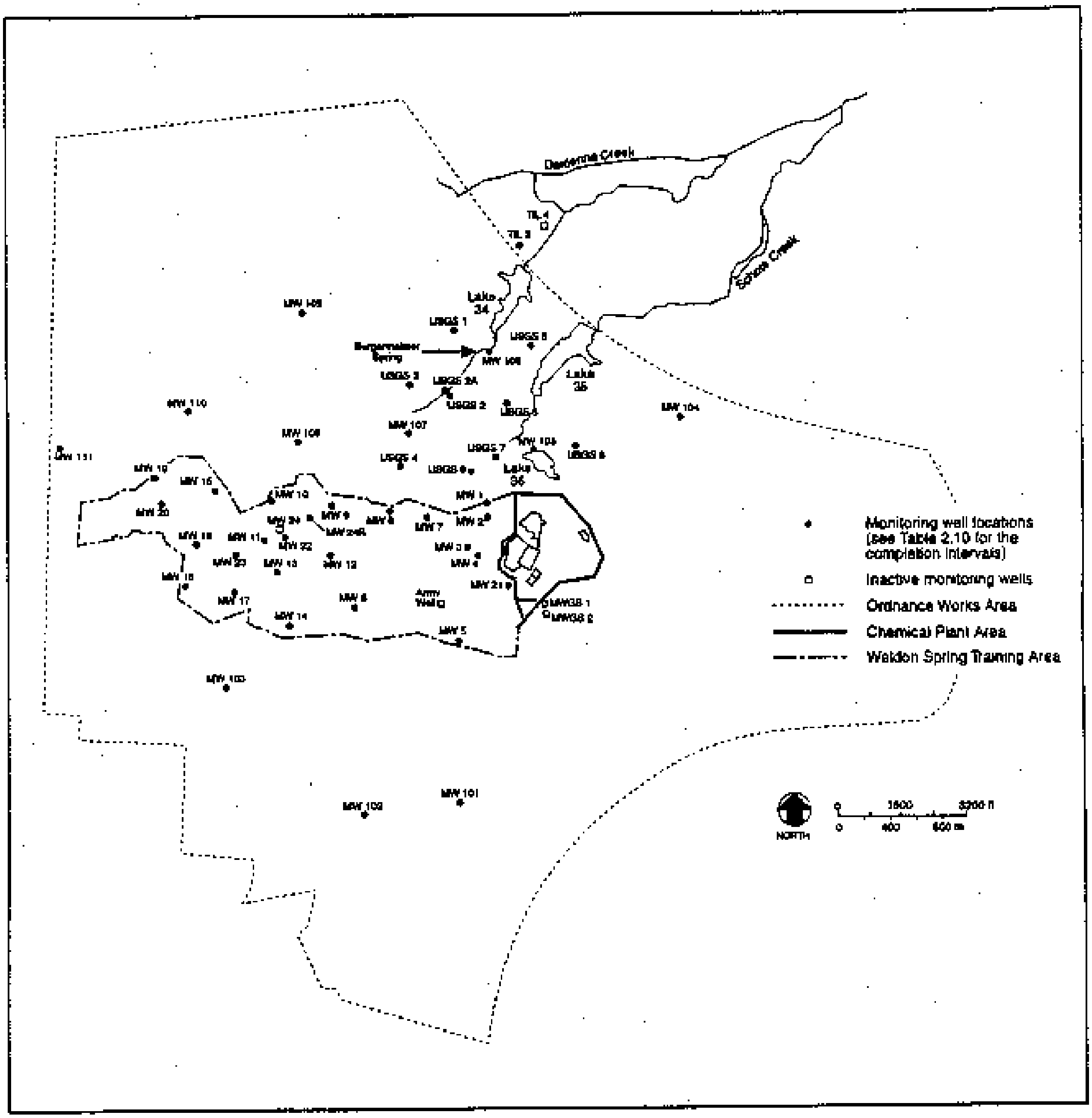


FIGURE 2.15 Monitoring Wells at the Ordnance Works Area

TABLE 2.11 Summary of Filtered Groundwater Data for the Ordnance Works Area[a]

	Weathered Wells				Unweathered Wells			
Metal	Detection Frequency	Range[b] (µg/L)	Mean[b] (µg/L)	Upper End[b] (µg/L)	Detection Frequency	Range[b] (µg/L)	Mean[b] (µg/L)	Upper End[b]
Aluminum	94/152	7.0-12,000	180	2,500	8/57	18-239	35	110
Antimony	64/152	1.7-140	16	86	24/57	1.7-140	23	110
Arsenic	39/169	0.50-20	2.8	8.4	22/62	0.50-10	2.7	6.7
Barium	169/169	38-530	150	350	62/62	10-300	150	230
Beryllium	5/152	0.20-4.0	1.1	2.9	1/57	0.20-3.0	1.0	2.8
Cadmium	28/169	0.20-13	2.0	8.0	8/62	0.20-12	2.0	7.4
Calcium	169/169	24,000-410,000	77,000	180,000	62/62	560-110,000	50,000	79,000
Chromium	14/169	2.0-54	5.7	16	5/62	2.0-10	5.0	11
Cobalt	12/152	2.3-33	8.2	22	2/57	2.3-33	8.7	25
Copper	32/152	1.0-18	4.0	10	9/57	1.0-8.0	4.0	6.0
Iron	53/152	7.0-19,000	170	3,200	30/57	7.0-210	34	110
Lead	35/169	0.70-88	8.0	36	6/62	0.70-88	10	50
Magnesium	169/169	6,300-170,000	25,000	66,000	62/62	24,000-42,000	33,000	41,000
Manganese	88/152	0.70-740	35	230	52/57	5.0-360	75	230
Mercury	6/169	0.10-1.0	0.20	0.60	1/62	0.10-3.0	0.30	1.1
Nickel	17/152	5.6-190	18	78	6/57	5.6-100	15	45
Potassium	47/169	900-5,300	1,700	3,000	12/62	900-2,000	1,600	2,500
Selenium	30/169	0.80-20	2.6	9.8	8/62	0.80-12	2.4	8.6
Silver	3/169	2.0-10	5.0	10	5/62	2.0-10	4.9	9.9
Sodium	169/169	4,700-180,000	17,000	67,000	62/62	4,800-29,000	7,100	14,000
Thallium[c]	9/129	0.9-40	2.0	10	0/46	0.90-4.0	1.9	4.1
Vanadium	20/152	2.0-29	5.3	12	6/57	2.0-14	5.3	12
Zinc	90/152	0.20-5,000	92	930	37/57	1.0-400	41	190

	Deep Wells[d]				USGS Wells[e]			
Metal	Detection Frequency	Range[b] (µg/L)	Mean[b] (µg/L)	Upper End[b] (µg/L)	Detection Frequency	Range[b] (µg/L)	Mean[b] (µg/L)	Upper End[b] (µg/L)
Aluminum	19/43	18-3,300	190	1,500	12/64	18-300	36	120
Antimony	16/42	1.7-140	26	110	30/64	0.40-140	23	120
Arsenic	24/46	0.60-30	4.7	16	12/64	0.50-9.0	2.1	5.5
Barium	48/48	23-560	200	440	64/64	76-430	160	290
Beryllium	2/42	0.20-3.0	1.0	2.8	0/64	0.20-3.0	1.1	3.0
Cadmium	7/46	0.20-10	2.1	7.9	6/64	0.20-10	2.0	8.0
Calcium	48/48	38,000-200,000	65,000	125,000	64/64	37,000-410,000	65,000	155,000
Chromium	6/48	2.0-18	5.4	13	5/64	2.0-45	6.0	17
Cobalt	1/42	2.3-33	9.5	27	6/64	3.0-33	9.7	29
Copper	9/42	1.0-16	4.0	12	13/64	1.0-30	4.0	12
Iron	22/43	7.0-8,900	1,100	6,500	32/64	8.0-16,000	290	4,200
Lead	10/45	0.70-88	11	55	11/64	2.0-100	16	78
Magnesium	48/48	20,000-61,000	31,000	51,000	64/64	17,000-50,000	30,000	42,000
Manganese	44/44	7.0-920	260	820	37/64	0.90-455	26	190
Mercury	2/47	0.10-5.5	0.40	2	2/64	0.10-0.30	0.20	0.32
Nickel	5/42	5.6-51	15	39	5/64	8.0-61	17	48
Potassium	34/48	93-17,000	4,400	12,000	14/64	900-3,100	1,600	2,800
Selenium	5/47	0.80-11	2.2	7.8	13/64	0.80-1.9	1.1	1.5
Silver	1/47	0.60-10	4.8	9.6	3/64	2.0-2,000	36	530
Sodium	48/48	5,800-87,000	16,400	48,000	64/64	4,600-30,000	10,000	23,000
Thallium[c]	1/33	0.90-40	4.0	22	9/58	0.90-130	8.0	62
Vanadium	11/42	2.0-14	6.4	14	7/64	2.0-14	6.0	14
Zinc	27/44	1.0-830	57	310	33/64	1.0-760	68	310

TABLE 2.11 (Cont.)

Metal	Vadose Zone Wells Detection Frequency	Range[b] (µg/L)	Mean[b] (µg/L)	Upper End[b] (µg/L)
Aluminum	12/37	2.0-210	41	120
Antimony	16/37	1.7-90	15	75
Arsenic	12/43	0.60-20	2.7	9.1
Barium	43/43	10-400	110	270
Beryllium	2/37	0.20-40	2.0	15
Cadmium	14/43	0.20-34	3.5	16
Calcium	43/43	20,000-340,000	96,000	270,000
Chromium	1/43	2.0-37	6.0	17
Cobalt	1/37	2.3-37	7.7	23
Copper	9/37	1.0-33	5.0	15
Iron	14/37	7.0-470	54	230
Lead	10/43	0.70-30	7.0	27
Magnesium	43/43	4,700-48,000	17,000	37,000
Manganese	24/37	1.0-300	37	200
Mercury	1/43	0.10-1.3	0.30	0.90
Nickel	3/37	5.6-100	14	46
Potassium	20/43	900-5,400	2,100	4,100
Selenium	4/43	0.80-50	4.2	21
Silver	2/43	2.0-29	5.6	14
Sodium	43/43	4,100-110,000	27,000	74,000
Thallium[c]	3/32	0.90-6.0	2.0	5.0
Vanadium	6/37	2.0-40	5.9	18
Zinc	17/37	1.0-100	34	104

[a] Summary includes data collected from March 1989 to May 1994.

[b] To facilitate comparison with background levels, the range, mean, and upper-end values given assume concentrations equal to the sample detection limits for values reported as not detected. Upper-end values are equal to the mean plus two standard deviations. Values are rounded to two significant figures.

[c] Not detected values that exceeded 100 µg/L were excluded as follows: weathered group, 23; unweathered group, 11; deep well group, 9; USGS group, 6; and vadose zone group, 5.

[d] Deep wells (i.e., wells open to units below the Burlington-Keokuk Limestone) include MWD 5, MWS 18, MWD 18, MWS 101, MWS 102, MWS 103, MWGS 1, MWGS 2, and the Army well.

[e] USGS wells include TIL 3 and TIL 4.

TABLE 2.12 Summary of Unfiltered Groundwater Data for the Ordnance Works Area[a]

Parameter	Weathered Wells: Detection Frequency	Weathered Wells: Range[b]	Weathered Wells: Mean[b]	Weathered Wells: Upper End[b]	Unweathered Wells: Detection Frequency	Unweathered Wells: Range[b]	Unweathered Wells: Mean[b]	Unweathered Wells: Upper End[b]
Radionuclides (pCi/L)								
Gross alpha	13/22	3.1-59	13	NA	6/12	2.2-43	16	NA
Gross beta	1/22	51	51	NA	3/12	5.8-21	13	NA
Metals (µg/L)								
Aluminum	158/168	18-58,000	4,000	21,000	68/62	18-15,000	1,300	6,500
Antimony	16/168	2.0-140	19	65	61/62	2.0-140	25	100
Arsenic	67/169	0.60-430	6.8	74	26/62	0.80-10	3.0	7.6
Barium	168/168	48-840	200	470	61/62	94-330	170	260
Beryllium	24/168	0.30-5.4	1.2	3.0	2/62	0.70-3.0	1.0	2.6
Cadmium	59/168	0.20-30	2.3	9.7	21/62	0.20-11	1.9	7.3
Calcium	168/168	34,000-880,000	98,000	270,000	61/62	30,000-1,000,000	95,000	390,000
Chromium	66/168	2.0-110	10	39	13/62	2.0-32	6.8	15
Cobalt	47/168	2.0-68	13	35	8/62	2.0-33	10	26
Copper	101/168	1.0-150	13	53	26/62	1.0-1203	10	46
Iron	164/168	8.0-42,000	5,300	24,000	60/62	6.0-18,000	1,600	7,300
Lead	98/168	0.40-88	12	44	24/62	0.70-88	13	53
Magnesium	168/168	7,400-160,000	26,000	72,000	61/62	24,000-140,000	33,000	74,000
Manganese	161/168	3.0-2,800	260	1,100	59/62	2.0-1,200	170	560
Mercury	16/169	0.10-5.6	0.30	1.3	3/62	0.10-1.0	0.20	0.60
Nickel	62/168	6.0-260	29	110	20/62	6.0-580	25	170
Potassium	68/168	900-9,000	1,900	3,800	14/62	900-2,600	1,600	2,600
Selenium	24/169	0.80-30	4.0	14	1/62	0.80-2.0	3.0	11
Silver	3/168	2.0-450	8.0	76	3/62	2.0-15	5.0	11
Sodium	168/168	4,300-180,000	17,000	69,000	61/62	4,800-28,000	6,900	14,000
Thallium[c]	20/145	0.90-80	6.3	32	5/51	0.90-120	7.4	46
Vanadium	73/168	2.0-96	11	39	20/62	2.0-34	7.0	17
Zinc	135/168	1.0-890	89	360	47/62	2.0 20	57	230
Inorganic anions (mg/L)								
Chloride	157/170	0.10-39	4.4	16	53/62	0.25-19	2.8	12
Fluoride	121/150	0.040-1.5	0.47	1.1	45/54	0.090-0.95	0.37	0.82
Nitrate (as N)	20/20	0.040-16	2.6	11	8/8	0.020-0.48	0.14	0.44
Sulfate	144/170	0.90-300	60	96	49/62	0.50-74	13	34
Nitroaromatic compounds (µg/L)								
1,3-DNB	10/310	0.26-35	4.0	NA	3/147	0.40-1.1	0.87	NA
2,4-DNT	29/310	0.050-35	3.4	NA	0/147	ND[d]	ND	NA
2,6-DNT	64/285	0.11-69	4.8	NA	2/135	0.060-0.10	0.080	NA
Aminodinitrotoluenes	5/24	0.0020-5.6	2.2	NA	0/12	ND	ND	NA
4-Amino-2,6-DNT	73/201	0.30-34	8.2	NA	2/94	0.30-0.38	0.34	NA
2-Amino-4,6-DNT	68/200	0.29-18	5.6	NA	0/94	ND	ND	NA
NB	18/301	0.29-2.0	0.80	NA	0/146	ND	ND	NA
m-Nitrotoluene	14/282	0.080-180	30	NA	0/141	ND	ND	NA
o-Nitrotoluene	22/283	0.050-85	16	NA	1/141	1.1	1.1	NA
p-Nitrotoluene	11/260	0.30-77	14	NA	0/129	ND	ND	NA
Nitrotoluene, total	1/19	1.2	1.2	NA	0/5	ND	ND	NA
1,3,5-TNB	92/310	0.26-31	5.8	NA	0/147	ND	ND	NA
2,4,6-TNT	77/310	0.30-12	3.1	NA	1/147	0.19	0.19	NA

TABLE 2.12 (Cont.)

Parameter	Deep Wells[d]				USGS Wells[e]			
	Detection Frequency	Range[b]	Mean[b]	Upper End[b]	Detection Frequency	Range[b]	Mean[b]	Upper End[b]
Radionuclides (pCi/L)								
Gross alpha	6/6	3.0-65	14	NA	10/10	2.0-10	7.0	NA
Gross beta	4/6	5.4-69	17	NA	0/10	ND	ND	NA
Metals (µg/L)								
Aluminum	46/47	50-27,000	4,800	17,000	51/64	18-73,000	1,700	20,000
Antimony	7/45	2.0-140	27	110	7/64	2.0-140	22	120
Arsenic	30/46	0.60-230	21	100	22/64	0.50-68	3.1	20
Barium	48/48	38-670	240	600	64/64	63-1,300	190	490
Beryllium	10/46	0.20-3.0	0.90	2.1	3/64	0.20-5.0	1.1	3.1
Cadmium	32/47	0.20-20	3.2	12	7/64	0.20-10	1.7	6.5
Calcium	48/48	10,000-620,000	130,000	340,000	64/64	2,100-260,000	74,000	160,000
Chromium	16/47	2.0-40	8.6	25	13/64	2.0-60	6.3	26
Cobalt	10/46	2.0-40	12	32	6/64	3.0-160	12	54
Copper	38/46	2.0-120	19	63	24/64	1.0-110	9.0	40
Iron	47/48	25-55,000	9,800	34,000	62/64	9.0-96,000	3,100	25,000
Lead	32/46	2.0-270	30	120	22/64	2.0-400	27	150
Magnesium	48/48	7,100-134,000	37,000	79,000	64/64	3,800-87,000	32,000	54,000
Manganese	48/48	3.0-1,800	460	1,200	64/64	1.3-3,700	120	1,100
Mercury	3/47	0.10-7.7	0.40	2.6	4/64	0.10-1.1	0.20	0.50
Nickel	16/46	6.0-130	24	70	7/64	8.0-68	18	50
Potassium	37/48	1,000-14,000	5,100	14,000	13/64	900-6,500	1,700	3,400
Selenium	6/46	0.80-72	4.0	26	10/64	0.80-2.0	1.0	2.0
Silver	1/46	2.0-75	6.0	28	0/64	0.20-10	5.0	11
Sodium	48/48	1,600-87,000	17,000	48,000	64/64	4,600-30,000	10,000	24,000
Thallium[c]	2/36	0.90-30	4.2	20	8/56	0.90-89	3.7	27
Vanadium	30/46	4.0-54	15	43	14/64	2.0-160	9.0	48
Zinc	39/48	7.9-380	95	260	46/64	1.0-1,600	110	590
Inorganic anions (mg/L)								
Chloride	44/46	0.80-27	5.3	17	58/64	0.30-6.0	1.7	4.2
Fluoride	36/39	0.10-1.7	0.71	1.6	46/55	0.040-2.1	0.56	1.5
Nitrate (as N)	7/7	0.040-1.2	0.29	1.1	9/9	0.020-3.2	1.1	3.6
Sulfate	40/46	0.40-420	42	180	60/64	0.55-32	16	32
Nitroaromatic compounds (µg/L)								
1,3-DNB	0/80	ND	ND	NA	1/109	0.080	0.080	NA
2,4-DNT	0/80	ND	ND	NA	6/109	0.30-3.9	1.9	NA
2,6-DNT	0/74	ND	ND	NA	12/109	0.060-3.6	1.8	NA
Aminodinitrotoluenes	0/6	ND	ND	NA	2/11	2.2-3.5	2.8	NA
4-Amino-2,6-DNT	0/52	ND	ND	NA	16/89	0.31-6.8	2.4	NA
2-Amino-4,6-DNT	0/52	ND	ND	NA	17/89	0.40-5.1	1.9	NA
NB	1/79	0.40	0.40	NA	1/109	0.40	0.40	NA
m-Nitrotoluene	3/76	0.080-0.63	0.40	NA	1/109	0.13	0.13	NA
o-Nitrotoluene	1/76	1.2	1.2	NA	5/109	0.29-0.80	0.62	NA
p-Nitrotoluene	0/70	ND	ND	NA	0/100	ND	ND	NA
Nitrotoluenes, total	0/3	ND	ND	NA	0/0	NT	NT	NA
1,3,5-TNB	0/80	ND	ND	NA	27/109	0.07-5.6	1.7	NA
2,4,6-TNT	1/80	6.8[f]	6.8[f]	NA	7/109	0.41-4.4	1.6	NA

TABLE 2.12 (Cont.)

	Vadose Zone Wells			
Parameter	Detection Frequency	Range[b]	Mean[b]	Upper End[b]
Radionuclides (pCi/L)				
Gross alpha	4/6	3.0-18	11	NA
Gross beta	3/6	10-18	10	NA
Metals (μg/L)				
Aluminum	42/43	30-81,000	11,000	44,000
Antimony	5/43	2.0-90	19	77
Arsenic	26/43	0.60-49	6.9	27
Barium	43/43	35-960	210	650
Beryllium	12/43	0.20-7.0	1.3	3.9
Cadmium	24/43	0.20-22	3.8	16
Calcium	43/43	21,000-590,000	120,000	360,000
Chromium	23/43	2.0-180	25	100
Cobalt	19/43	2.0-50	13	33
Copper	32/43	1.0-93	18	58
Iron	43/43	20-160,000	20,000	81,000
Lead	28/43	2.0-180	26	99
Magnesium	43/43	5,300-54,000	16,000	41,000
Manganese	41/43	2.2-4,300	7,400	2,600
Mercury	4/43	0.10-1.0	0.30	0.90
Nickel	26/43	6.0-270	40	140
Potassium	27/43	1,000-7,000	2,900	6,300
Selenium	1/43	0.80-30	4.0	16
Silver	0/43	2.0-10	5.0	9.0
Sodium	43/43	3,500-110,000	25,000	72,000
Thallium[c]	4/38	0.90-460	18	170
Vanadium	31/43	3.0-180	29	110
Zinc	36/43	4.0-2,000	160	790
Inorganic anions (mg/L)				
Chloride	40/43	0.20-19	5.5	15
Fluoride	31/37	0.040-1.7	0.47	1.2
Nitrate (as N)	5/6	0.050-5.7	1.5	6.7
Sulfate	38/43	1.0-640	130	620
Nitroaromatic compounds (μg/L)				
1,3-DNB	6/80	0.27-2.2	0.69	NA
2,4-DNT	21/80	0.050-35	14	NA
2,6-DNT	21/74	0.11-69	6.9	NA
Aminodinitrotoluenes	2/5	6.8-52	29	NA
4-Amino-2,6-DNT	22/49	0.30-53	14	NA
2-Amino-4,6-DNT	20/49	1.1-44	14	NA
NB	17/80	0.30-14	4.9	NA
m-Nitrotoluene	5/73	0.060-170	34	NA
o-Nitrotoluene	10/73	0.14-65	10	NA
p-Nitrotoluene	3/68	0.30-17	5.9	NA
Nitrotoluenes, total	0/7	ND	ND	NA
1,3,5-TNB	25/80	0.30-29	12	NA
2,4,6-TNT	37/80	0.12-84	16	NA

[a] Summary includes data collected from March 1989 to May 1994.

[b] For radionuclides and nitroaromatic compounds, the range and mean of concentrations at or above the detection limit are given; NA indicates that no upper-end values are given because these values are not compared with background values. For metals and inorganic anions, to facilitate comparison with background levels, the range, mean, and upper-end values given assume concentrations equal to the sample detection limits for values reported as not detected. Upper-end values are equal to the mean plus two standard deviations. Values are rounded to two significant figures. ND indicates not detected; NT indicates not tested.

[c] Not detected values that exceeded 100 μg/L were excluded as follows: weathered group, 23; unweathered group, 11; deep well group, 9; USGS group, 8; and vadose zone group, 5.

[d] Deep wells (i.e., wells open to units below the Burlington-Keokuk Limestone) include MWD 5, MWS 18, MWD 18, MWS 101, MWS 102, MWS 103, MWGS 1, and MWGS 2.

[e] USGS group includes TIL 3 and TIL 4 wells.

[f] Confirmatory sampling did not indicate the presence of TNT.

concentration limit excludes the contribution from uranium and radium-226. Because isotopic data are not available, fully interpreting these data is not possible. The EPA does not specify a limit for gross beta.

In the wells open to the weathered zone of the Burlington-Keokuk Limestone, gross alpha levels exceeded 15 pCi/L in two wells located north of the training area: 53 pCi/L in MWS 111 and 16 pCi/L in MWS 110. In the unweathered Burlington-Keokuk, gross alpha exceeded the MCL in two locations. The concentration detected in well MWS 6, located in the training area, was 43 pCi/L; and the concentration in MWD 109, located north of the training area, was 16 pCi/L. Gross alpha levels exceeding 15 pCi/L were detected in three of the deep wells, with levels of 19, 65, and 30 pCi/L measured in wells MWS 101, MWS 102, and MWS 103, respectively. It is unlikely that these wells have been directly impacted from activities associated with the chemical plant area. These wells are also not located directly downgradient of the chemical plant area. Wells MWS111 and MWD109 were selected as representing background conditions (see Section 2.4.3). For comparative purposes, all of the gross alpha levels detected were within the range measured by the Missouri Department of Health in off-site residential wells (Clardy 1995); however, all residential wells with gross alpha levels exceeding 10 pCi/L were at a depth of 61 m (200 ft) or greater.

Because of the limited amount of data collected and the lack of analyses for specific radionuclides, no conclusions were reached concerning radioactive contamination at the ordnance works area. Additional samples have been collected and will be analyzed for uranium as part of the joint DOE-CE sampling program (see Chapters 1 and 4).

2.4.5.2 Chemical Contaminants

Metals. Groundwater samples from the ordnance works area were analyzed for the same set of metals as those for the chemical plant area — except for lithium and molybdenum, which were not assayed in the samples from the ordnance works area. In general, the highest concentrations in the shallow groundwater system were detected in samples from wells completed in the upper weathered unit of the Burlington-Keokuk Limestone; however, the highest concentrations of antimony, barium, beryllium, mercury, nickel, and thallium were detected in the unweathered zone.

As a preliminary indicator of elevated metal concentrations in groundwater, the upper-end concentrations of metals in monitoring wells of the ordnance works area (Tables 2.11 and 2.12) were compared with upper-end background concentrations (Tables 2.3 and 2.4). Again, values for the ordnance works area that are more than twice the background values may be considered indicative of elevated groundwater concentrations for specific metals, although the results of the joint sampling effort will be used to further examine these data in the RI. For upper-end values from the ordnance works area that were between one and two times the background upper-end value, the results are considered uncertain because the statistical significance of the difference is questionable. Values from the deep wells were compared with background data for the unweathered unit, and values for the USGS well group were compared with background data for the weathered unit.

For the filtered data in the weathered and unweathered well groups, the following metals were above background concentrations in at least one group: aluminum, iron, manganese, mercury, nickel, thallium, and zinc. The results for chromium were uncertain in both well groups. For the unfiltered data in the weathered and unweathered well groups, the following metals were above background: aluminum, arsenic, calcium, chromium, iron, manganese, nickel, silver, and thallium.

The data from the deep well group were compared with background data for the unweathered unit on the assumption that naturally occurring substances would be found at approximately the same levels in these formations. Interestingly, on the basis of this comparison, the levels of most of the metals appeared to be either elevated or questionably elevated in the deep group. Possibly, actual background levels for the deeper formations (data not available) are higher than those for the unweathered zone of the Burlington-Keokuk Limestone, in which case the comparison with unweathered Burlington-Keokuk background values would not be valid.

Except for barium, copper, selenium, and zinc, the maximum detected concentrations of metals in unfiltered samples from wells completed in the weathered zone exceeded existing standards (Table 2.13). The analytical results for unfiltered samples from wells completed in the unweathered zone indicated that antimony, cadmium, lead, nickel, and thallium exceeded MCLs or MCLGs; however, in most cases, exceedances of standards occurred in only one of several sampling rounds in any given well.

The number of metals with maximum detected concentrations exceeding drinking water standards was considerably lower for filtered samples. The metals with detected concentrations below the drinking water standards in both weathered and unweathered well groups included arsenic, barium, beryllium, chromium, copper, selenium, silver, and zinc. Nickel exceeded the standard in the weathered group but not in the unweathered group, whereas mercury exceeded the standard in the unweathered group but not in the weathered group.

Detection frequencies were generally low (ranging from 2 to 6%) for beryllium, mercury, silver, and thallium; unfiltered samples for the weathered well group had a somewhat higher detection frequency for beryllium, mercury, and thallium (about 10%).

Although antimony did not appear to be elevated overall above background levels in filtered samples, the concentrations in some samples exceeded criteria levels. Some of the concentrations reported for antimony in the filtered samples are suspect because an analysis of the filters used indicated the presence of antimony. The detection frequency for antimony was about 40% in filtered samples and 9% in unfiltered samples, supporting the possibility that antimony was present on the filters. Nonetheless, the highest concentrations of antimony were reported for unfiltered samples, so groundwater contamination may be present. Thallium concentrations were elevated in unfiltered samples but were generally at or below the MCL value of 2 µg/L in filtered samples.

TABLE 2.13 Comparison of Groundwater Contaminant Concentrations at the Ordnance Works Area with Regulatory Standards[a]

Contaminant	Maximum Detected Concentration in Groundwater[b] (3/89-5/94 data)		EPA Drinking Water Regulations			Missouri Safe Drinking Water Act	
	Filtered	Unfiltered	MCL	MCLG	SMCL	MCL	SMCL
Metals (µg/L)							
Aluminum	12,000	58,000	-	-	50-200	-	50-200
Antimony	26	30	6	6	-	6	-
Arsenic	30	430	50[c]	-	-	50	-
Barium	560	840	2,000	2,000	-	2,000	-
Beryllium	3.0	5.4	4	4	-	4	-
Cadmium	13	30	5	5	-	5	-
Chromium	54	110	100	100	-	100	-
Copper	30	150	-	1,300[d]	1,000	1,300[d]	1,000
Iron	19,000	65,000	-	-	300	-	300
Lead	65	75	15[d]	0	-	15[d]	-
Manganese	920	3,700	-	-	50	-	50
Mercury	5.5	5.5	2	2	-	2	-
Nickel	190	580	100	100	-	100	-
Selenium	19	19	50	50	-	50	-
Silver	10	450	-	-	100	-	100
Thallium	130	120	2	0.5	-	2	-
Zinc	1,300	1,600	-	-	5,000	-	5,000
Inorganic anions (mg/L)							
Chloride	NA	39	-	-	250	-	250
Fluoride	NA	1.7	4[c]	4[c]	2[c]	4.0	2
Nitrate (as N)	NA	16	10	10	-	10	-
Sulfate	NA	420	500	500	250	-	250

Contaminant	Maximum Detected Concentration in Groundwater (3/89-5/94 data)		Health Advisory Levels[e]
	Filtered	Unfiltered	
Nitroaromatic compounds (µg/L)			
1,3-DNB	NA	35	1
2,4-DNT	NA	35	0.05
2,6-DNT	NA	69	0.05
2,4,6-TNT	NA	12	1

[a] Notation: NA = not available; MCL = maximum contaminant level; MCLG = maximum contaminant level goal; and SMCL = secondary maximum contaminant level. A hyphen indicates that no standard exists for that parameter.

[b] Excludes vadose zone wells, which are not representative of the Burlington-Keokuk aquifer.

[c] Under review.

[d] Treatment technology action level.

[e] Health advisory levels are nonenforceable health-risk-based guidelines derived by the EPA (1995). The reference document provides health advisory levels for carcinogens equivalent to a 10^{-4} risk level; these levels have been converted to a 10^{-6} risk level for use in this table.

Sources: EPA (1995); Missouri Department of Natural Resources (1993).

For the filtered samples, the maximum concentrations of cadmium, mercury, and nickel exceeded the MCLs or MCLGs. Levels of cadmium exceeding the MCL of 5 µg/L never occurred more than once in any given well, so no pattern of contamination is evident. Mercury occurred at a concentration exceeding the MCL of 2 µg/L in a sample from a well completed in the unweathered unit; the other 10 detected levels of mercury were below the MCL and occurred in different wells. Nickel concentrations ranging from 120 to 191 µg/L were detected in all five samples from MWS 21, indicating a possible source of contamination near this well.

Average levels of aluminum, iron, and manganese exceeded SMCL values in filtered and unfiltered samples collected from wells completed in both the weathered and unweathered Burlington-Keokuk Limestone. Generally, the upper range of these metal concentrations was also greater than the upper range of local background values (Table 2.4).

Although the focus of the GWOUs is on water quality in the weathered and unweathered portions of the Burlington-Keokuk, data for wells open to the deeper formations and the vadose zone are also included in Tables 2.11 and 2.12 for completeness. In general, the USGS wells, which are open to the Burlington-Keokuk Limestone and located north of the training area, have metal concentrations similar to those wells open to the weathered unit of the Burlington-Keokuk Limestone. Table 2.14 lists constituents from the ordnance works area that did not exceed the EPA criteria or exceeded the criteria only once in wells for which the number of samples was sufficient to confirm that the exceedance was nonrepresentative. These constituents are unlikely to represent a human health risk in the groundwater of the ordnance works area.

Inorganic Anions. Relative to the metals and other inorganic anions, the number of samples analyzed for nitrate is small (23 samples); however, only one groundwater sample, which was collected from well MWS 11, located in the central portion of the training area, had a detected concentration (16 mg/L) exceeding the MCL of 10 mg/L. No other nitrate analyses were performed on groundwater samples collected from this well.

The data for the other inorganic anions — chloride, fluoride, and sulfate — are more extensive. Detected concentrations of chloride and fluoride do not exceed drinking water standards. Levels of sulfate exceeded the SMCL value of 250 mg/L once in MWS 14 (weathered) and twice in MWS 18 (deep). Other sulfate concentrations were below the SMCL value (except for well MWS 13, which is being used as a preliminary background well; several concentrations in MWS 13 also exceeded the MCL value of 500 mg/L).

Nitroaromatic Compounds. In addition to the six nitroaromatic compounds analyzed in groundwater at the chemical plant area, groundwater samples from the ordnance works area have been tested for other nitroaromatic compounds that are degradation products of TNT and DNT. All of the nitroaromatic compounds analyzed in groundwater have been detected in wells completed in the weathered portion of the Burlington-Keokuk

TABLE 2.14 Constituents at the Ordnance Works Area that Do Not Exceed EPA Criteria[a]

Substance	Rationale
Barium	No unfiltered or filtered samples from the ordnance works area exceeded the MCL of 2,000 µg/L. One unfiltered sample from background well MWD 106 had a barium concentration of 14,000 µg/L. Concentrations in this well in seven other sampling rounds ranged from 130 to 170 µg/L. The number of samples is sufficient to show that the elevated level was an outlier, but this assumption will be confirmed in the joint sampling effort.
Beryllium	Two of 383 unfiltered samples exceeded the MCL of 4 µg/L; no concentrations in filtered samples exceeded the MCL. Beryllium was detected in two of eight samples from MWS 8, at concentrations of 5.4 and 2 µg/L; the other six samples were reported as not detected. Beryllium was detected in one of six samples from USGS 6, at a concentration of 5 µg/L; the other five samples were reported as not detected. The number of samples is sufficient to confirm that levels are below the MCL.
Copper	Maximum concentration was 150 µg/L; MCL is 1,300 µg/L; detection frequency 20%.
Chloride	Maximum concentration was 39 mg/L; SMCL is 250 mg/L; detection frequency 90%.
Chromium	One of 383 unfiltered samples exceeded the MCL of 100 µg/L; no concentrations in filtered samples exceeded the MCL. Chromium was detected in two of eight samples from well MWS 3, at concentrations of 110 and 7 µg/L; the six other samples were reported as not detected. The number of samples is sufficient to confirm that levels are below the MCL.
Fluoride	Maximum concentration was 1.5 mg/L; MCL is 4 mg/L; detection frequency 80%.
Silver	One of 383 unfiltered samples exceeded the MCL of 100 µg/L; no concentrations in filtered samples exceeded the MCL. Silver was detected in one of eight samples from MWS 2 at a concentration of 446 µg/L; the other seven samples were reported as not detected. The number of samples is sufficient to confirm that the levels are below the MCL.
Selenium	Maximum concentration was 19 µg/L; MCL is 50 µg/L; detection frequency 15%.
Zinc	Maximum concentration was 1,300 µg/L; MCL is 5,000 µg/L; detection frequency 55%.

[a] Only data for the weathered, unweathered, deep, and USGS well groups were evaluated; data from wells in the vadose zone are not applicable because they are not representative of the aquifer.

Limestone. The detection frequencies are greatest for 4-amino- 2,6-DNT (36%) and 1,3,5-TNB (30%). The nitroaromatic compound with the highest concentration is *m*-nitrotoluene, with a maximum detected concentration of 180 µg/L in MWS 12. Wells MWS 107 and MWS 110 in the ordnance works area north of the training area contain nitroaromatic compounds. Maximum levels of 1,3-DNB; 2,4-DNT; 2,6-DNT; and 2,4,6-TNT in wells open to the weathered Burlington-Keokuk exceeded EPA (1995) health advisory levels. The average detected concentrations of 1,3-DNB; 2,4-DNT; 2,6-DNT; and 2,4,6-TNT are shown in Figures 2.11 through 2.14, respectively.

To date, detections of nitroaromatic compounds in the unweathered portion of the shallow groundwater system have been sporadic and at low concentrations; however, three nitroaromatic compounds have been detected consistently in MWS 106 and MWD 9, indicating groundwater contamination. Also, nitroaromatics have been detected once each in MWS 5 and MWD 2. The nitroaromatic compounds NB and 1,3,5-TNB have been detected at low concentrations in wells in the deeper formations. A single detection of TNT at 6.8 µg/L in a deep well could not be confirmed by subsequent sampling. Maximum levels of 1,3-DNB and 2,6-DNT in wells open to the unweathered Burlington-Keokuk Limestone exceeded health advisory levels (EPA 1995).

Organic Contaminants. During the first round of sampling, wells were tested for volatile and semivolatile organic compounds (IT Corporation 1993a). 1,1,1-Trichloroethane was detected in one sample at a concentration of 40 µg/L; however, this detection was confirmed to be a laboratory error. Carbon disulfide and toluene, which were detected at low concentrations (up to 14 µg/L), are common laboratory contaminants. Carbon disulfide was detected in associated method blanks and was therefore not thought to be a potential contaminant. Toluene was detected in one sample from well MWS 5 at a concentration of 14 µg/L. Although toluene was used in the production processes at the ordnance works, it was not considered to be a potential site contaminant because of the low concentration and its potential to be a laboratory contaminant; however, because toluene has subsequently been detected in a process line, new analyses (i.e., one round of sampling included as part of the joint sampling) will be conducted for the wells with previous detections of carbon disulfide and toluene.

In the most recent round of sampling at the ordnance works area, samples were also analyzed for the explosive substances hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX; royal demolition explosive), *N*-methyl-*N*-2,4,6-tetranitroaniline (Tetryl), and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX). These substances were not detected in any groundwater samples.

2.4.6 Springs

Drainages that may have been impacted from sources on the chemical plant and ordnance works areas include the 5100, 5200, 5300 (Southeast Drainage), 5400, 5500, 5600, 6300 (Burgermeister Spring valley), 6500, and 6600 drainages. The major springs in each of these drainages have been sampled at least once by the either the Army or DOE; the results of these studies are summarized in the following paragraphs.

Surface water in the Southeast Drainage (5300) has been sampled and analyzed for radioactive and chemical contaminants at four springs as part of the Weldon Spring site environmental monitoring program. Surface water has been analyzed for uranium, radium, thorium, inorganic anions, metals, and nitroaromatics. Radioactive contamination in surface water is limited to uranium. The average concentrations of total uranium measured at the springs are 290 pCi/L for SP-5301, 260 pCi/L for SP-5302, and 160 pCi/L for SP-5303 and SP-5304.

Low levels of nitroaromatic compounds have been measured at SP-5303 and SP-5304. The principal nitroaromatic compound found in the drainage is TNT, which has been detected in SP-5303 at a maximum concentration of 21 µg/L and an average concentration of 13 µg/L. Prior to 1990, a TNT level of 280 µg/L was also measured at this spring. Low levels of 2,4-DNT; 2,6-DNT; and TNB have also been detected in the springs; but the concentrations were below 0.5 µg/L. The Army has also monitored SP-5304 for nitroaromatics and metals. The major contaminant detected was TNT, at a concentration of 34 µg/L (IT Corporation 1993a).

Other springs in the ordnance works area have been sampled by the Army (IT Corporation 1992a, 1993a) and DOE (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1989b). Results of these investigations indicate widespread low-level nitroaromatic contamination in the drainages located south of the training area, with higher concentrations detected in the vicinity of known source areas. The highest concentrations of nitroaromatics were detected in drainage 5200, downgradient of Burning Ground 1, which has the highest levels of nitroaromatic soil contamination. The maximum concentration of TNT measured at SP-5201 was 67 µg/L. In the northern portion of the ordnance works area, three drainages were investigated: 6300, 6500, and 6600. Except for a single detection at SP-6601, measured at just above the detection limit, nitroaromatic contamination was limited to drainage 6300, the Burgermeister Spring drainage.

Samples of springs have also been analyzed for metals, inorganic anions, volatile organic compounds, and radionuclides. Slightly elevated levels of some metals, chloride, and sulfate have been measured in some of the springs. No volatile organic compounds have been detected.

Burgermeister Spring, located in the 6300 drainage, has been routinely monitored by both the Army and DOE because this spring appears to be a major groundwater discharge area for drainage from both the training area and the chemical plant area. Surface water at Burgermeister Spring is monitored quarterly for radioactive and chemical contaminants as part of the environmental monitoring program for the chemical plant area. These data are presented in Table 2.15. The primary contaminant at Burgermeister Spring is uranium, which has been detected at concentrations ranging from 6.3 to 140 pCi/L. The average concentration measured over the past three years is 66 pCi/L. Other contaminants measured

TABLE 2.15 Summary of Surface Water Data for Burgermeister Spring[a]

Contaminant	Detection Limit	Detection Frequency	Concentration Range[b]
Radionuclides (filtered samples, pCi/L)			
Gross alpha	2.0-15	3/3	38-79
Gross beta	4.0-11	3/3	13-19
Radium-226	0.30-1.8	3/5	0.3-0.48
Radium-228	1.0-3.5	3/5	1.0-4.0
Thorium-228	0.10-0.40	0/5	ND[c]
Thorium-230	0.05-0.83	2/5	0.14-0.36
Thorium-232	0.05-0.40	1/5	0.12
Uranium, total	0.20-0.68	20/20	6.3-140
Metals (filtered samples, μg/L)			
Aluminum	18-120	3/13	30-140
Antimony	1.7-90	4/12	3.0-5.0
Arsenic	0.90-3.4	1/14	1.0
Barium	2.0-44	14/14	62-160
Beryllium	0.20-3.0	0/12	ND
Cadmium	0.20-10	1/12	0.6
Calcium	17-110	13/13	32,000-110,000
Chromium	2.0-10	1/13	10
Cobalt	2.3-20	0/12	ND
Copper	1.0-10	1/12	2.3
Iron	7.0-27	10/13	10-970
Lead	2.0-22	2/13	0.8-4.0
Lithium	8.4-100	0/6	ND
Magnesium	44-110	13/13	5,900-29,000
Manganese	0.6-10	8/13	2.0-980
Mercury	0.10-0.20	0/12	ND
Molybdenum	18-100	0/5	ND
Nickel	5.6-27	0/13	ND
Potassium	310-900	13/13	1,600-3,300
Selenium	1.0-10	4/12	1.8-2.7
Silver	1.0-10	1/12	6.0
Sodium	47-190	13/13	6,600-46,000
Thallium	1.0-300	0/12	ND
Vanadium	2.0-9.0	3/12	2.0-16
Zinc	1.0-100	8/12	4.0-21
Metals (unfiltered samples, μg/L)			
Aluminum	-[c]	7/7	60-1,300
Antimony	1.7-90	1/7	5.0
Arsenic	0.60-10	1/7	2.0
Barium	-	7/7	69-161
Beryllium	0.2-3.0	0/7	ND
Cadmium	0.2-10	0/7	ND
Calcium	-	7/7	29,000-118,000
Chromium	2.0-10	0/7	ND
Cobalt	2.0-20	0/7	ND
Copper	1.0-6.0	2/7	2.0
Iron	-	7/7	70-1,100
Lead	2.0-22	1/7	0.9

TABLE 2.15 (Cont.)

Contaminant	Detection Limit	Detection Frequency	Concentration Range[b]
Metals (unfiltered samples, µg/L) (cont.)			
Magnesium	-	7/7	5,900-31,000
Manganese	5.0-10	5/7	6.3-160
Mercury	0.10-0.20	0/7	ND
Nickel	6.0-20	0/7	ND
Potassium	-	7/7	2,400-3,300
Selenium	1.0-10	2/7	2.0
Silver	2.0-10	0/7	ND
Sodium	-	7/7	6,600-46,000
Thallium	1.0-300	0/7	ND
Vanadium	2.0-8.0	1/7	4.0
Zinc	1.0-100	2/7	3.0-6.0
Inorganic anions (mg/L)			
Chloride	0.05-0.25	12/12	4.6-32
Fluoride	0.5	6/8	0.13-0.79
Nitrate (as N)	0.01-5.0	16/19	1.6-210
Nitrite (as N)	0.01-0.10	0/3	ND
Sulfate	1.2-25	23/23	12-140
Nitroaromatic compounds (µg/L)			
1,3-DNB	0.09-10	0/18	ND
2,4-DNT	0.030-6.0	5/17	0.03-0.068
2,6-DNT	0.010-6.0	7/16	0.20-0.48
NB	0.030-10	0/17	ND
1,3,5-TNB	0.030-6.0	4/17	0.031-0.088
2,4,6-TNT	0.030-6.0	7/17	0.041-0.29
Aminodinitrotoluenes	-	1/1	0.82
4-Amino-2,6-DNT	0.25-0.30	1/5	2.0
2-Amino-4,6-DNT	0.25-0.30	2/5	0.40-0.71
m-Nitrotoluene	0.25-0.56	0/8	ND
o-Nitrotoluene	0.25-0.36	0/8	ND
p-Nitrotoluene	0.25-0.60	0/8	ND

[a] Data are the combined results from investigations at the chemical plant area and the ordnance works area. Results for filtered and unfiltered samples were combined for inorganic anions and nitroaromatic compounds.

[b] The concentration range is for detected values only; a single value is given if the contaminant was detected in only one sample.

[c] ND = not detected; a hyphen indicates that the detection limit is unknown.

at elevated concentrations include nitrate and nitroaromatic compounds. Nitrate has been measured at concentrations ranging from 1.6 to 210 mg/L, with a three-year average concentration of 32 mg/L. Very low levels of 2,4-DNT; 2,6-DNT; 1,3,5-TNB; and 2,4,6-TNT have been detected in Burgermeister Spring. In 1992, the spring was monitored during high and low flow to determine the effect on contaminant levels. Levels of uranium did not correlate with flow, but nitrate levels decreased at high flow.

Eight water samples from Burgermeister Spring have also been analyzed as part of the Army area monitoring program. Filtered and unfiltered samples have been analyzed for metals, nitroaromatic compounds, and inorganic anions. Of the nitroaromatic compounds, aminodinitrotoluenes were detected in three samples at concentrations ranging from 0.4 to 2 µg/L. Concentrations of nitroaromatic compounds were below levels reported to be toxic to aquatic biota (DOE 1992a). Concentrations of metals and inorganic anions were all less than state and federal primary drinking water standards, although maximum levels of aluminum, iron, and manganese exceeded SMCLs in unfiltered samples. Several metals were present at levels that exceeded the state of Missouri AWQC (Missouri Department of Natural Resources 1992) or the EPA (1986) AWQC for the protection of freshwater biota or were measured with method detection limits exceeding the AWQC. These metals include cadmium, lead, mercury, silver, and thallium. Selenium was detected at concentrations below the state of Missouri AWQC but within the range reported to be toxic to waterfowl (Lemly and Smith 1987).

Sediment at Burgermeister Spring has also been characterized (Boerner 1986; MK-Ferguson Company and Jacobs Engineering Group, Inc. 1989a) and is summarized in Table 2.13 of the BA for the chemical plant area (DOE 1992a). A limited number of samples were analyzed for radium-226, radium-228, uranium-238, CLP metals, nitroaromatics, PCBs, and semivolatiles. Contaminant concentrations were compared with levels measured in Lake 37, an uncontaminated lake in the August A. Busch Memorial Conservation Area. Of the radionuclides, only uranium was detected at elevated concentrations: a high of 22 pCi/g was detected in one sample; other measurements were below 2.6 pCi/g. In general, most of the metals have been detected within or slightly above the range of natural background levels. The maximum arsenic and lead concentrations (19 and 35 mg/kg, respectively) were measured at two to three times the maximum background concentrations (5.0 and 17 mg/kg, respectively). Nitroaromatics, PCBs, and semivolatiles were not detected.

3 INITIAL SITE EVALUATION

3.1 SITE CONCEPTUAL EXPOSURE MODELS

Site conceptual exposure models were developed to identify source areas for contaminants, potential release and transport mechanisms, environmental media of concern, potential human receptors, and routes of exposure for the GWOUs. The models summarize existing data for the chemical plant area and the ordnance works area, identify data requirements, and provide the rationale for the development of sampling plans to be used in the RIs. As additional data become available, the conceptual models will be revised. The site conceptual exposure models for the GWOUs are shown in Figures 3.1 and 3.2; components of the models are described in Sections 3.1.1 through 3.1.5.

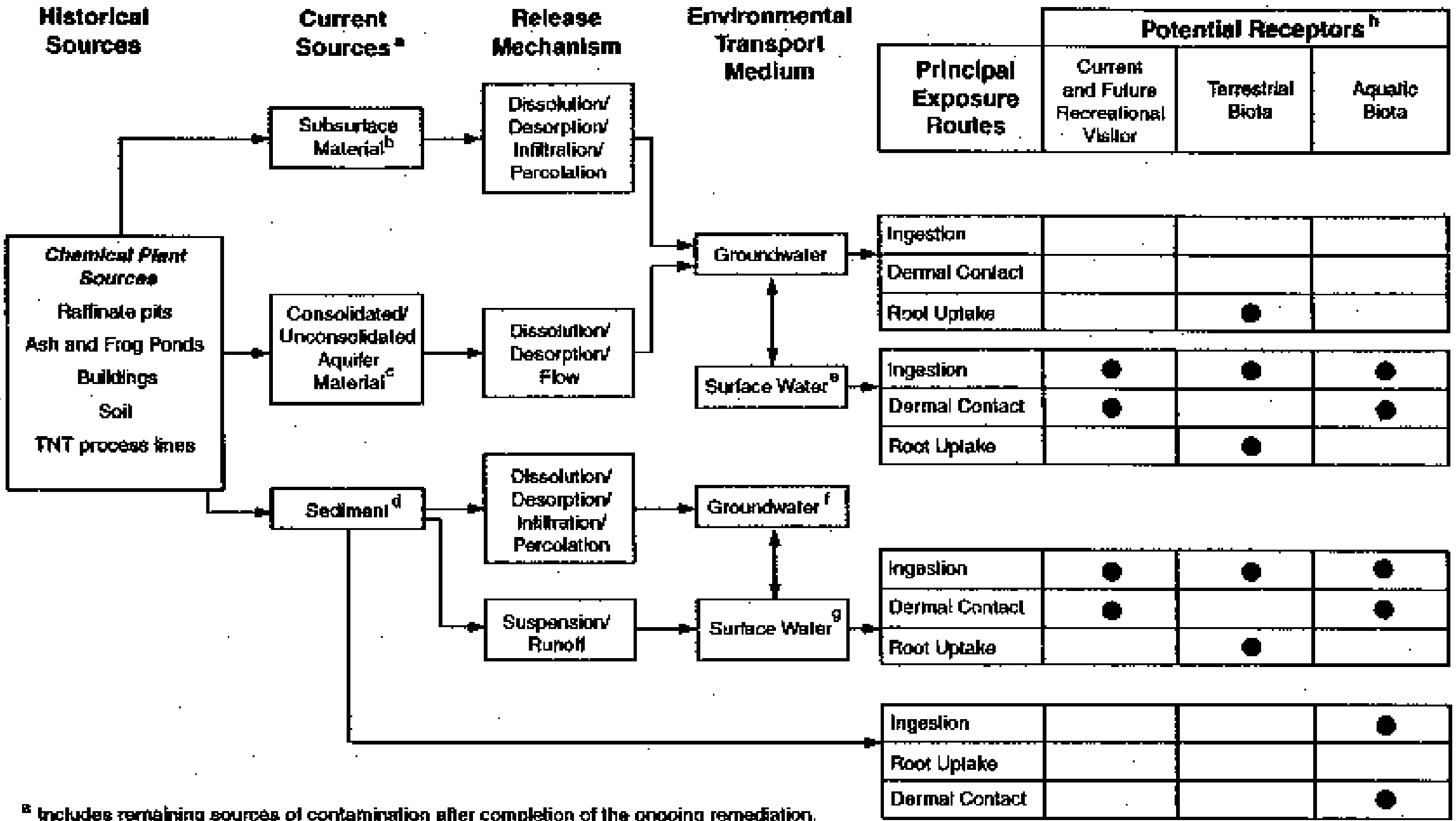
3.1.1 Contaminant Sources

A number of historical sources have been identified for the chemical plant area GWOU, including the raffinate pits, Ash and Frog Ponds, buildings, soil, and TNT process lines (Figure 3.1). After completion of remedial activities associated with previous decisions for the chemical plant area, three sources of contamination will remain: contaminated subsurface material in the vadose zone (contaminants sorbed onto soil particles under unsaturated conditions); contaminated consolidated rock and unconsolidated residuum in the phreatic zone (contaminants sorbed onto material under saturated conditions); and contaminated sediment within the conduit to Burgermeister Spring (Figure 3.1).

For the ordnance works area GWOU, the following historical sources have been identified: TNT and DNT production lines (washhouses, grainer houses, settling tanks, tramways, and nitrating houses), three wastewater treatment plants (the fourth plant was never operational), in-line settling tanks, sellite/acid plants, burning grounds, a laboratory building, Mechanical City, storage bunkers, regraining area, dumps, lagoons, and buried wooden pipelines (Figure 3.2). After completion of planned remedial activities, the following sources will remain for this GWOU: sorbed contaminants on soil particles under unsaturated conditions; contaminants sorbed onto material under saturated conditions; and contaminated sediment within the conduit to Burgermeister Spring.

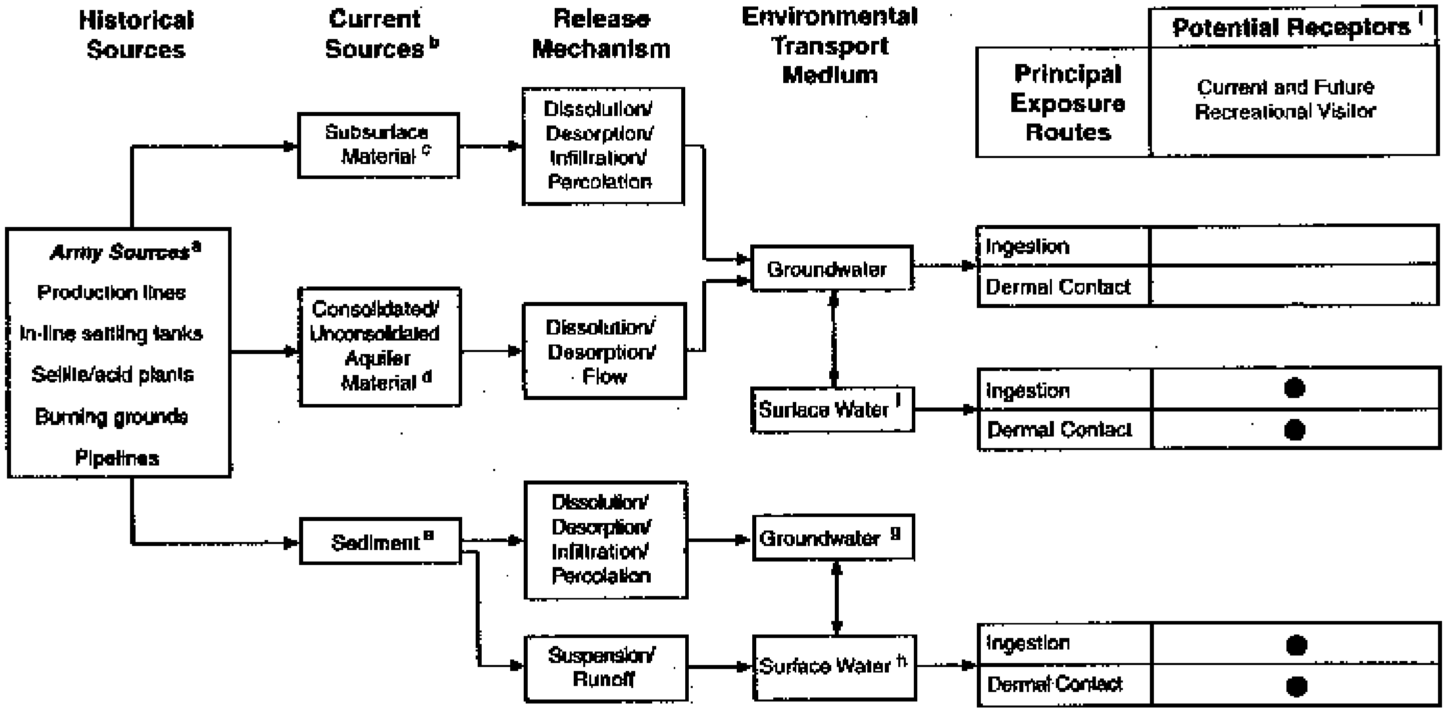
3.1.2 Radioactive and Chemical Contaminants

The information on the nature and extent of contamination presented in Section 2.4 represents a substantial database on contaminant levels in groundwater and surface water at the chemical plant area and the ordnance works area. The groundwater monitoring systems for these areas were designed to monitor major source areas associated with the sites. For the chemical plant area, the data collected from June 1990 to December 1993 serve as the basis for evaluation of potential site contaminants in groundwater and surface water.



[a] Includes remaining sources of contamination after completion of the ongoing remediation.
[b] Includes sorbed contaminants in the vadose zone.
[c] Includes the sorbed contaminants within the shallow unconfined aquifer.
[d] Includes sediment within the Burgermeister Spring conduit system.
[e] Includes surface water and sediment at Burgermeister Spring and the Southeast Drainage; contaminated sediment at the Southeast Drainage is being addressed as a separate action.
[f] No potential receptor; serves as transport medium to the surface water.
[g] Includes surface water at Burgermeister Spring and the Southeast Drainage.
[h] A future resident is not considered to be a plausible scenario; calculations for this scenario will be included in the risk assessment for comparative purposes. Potential pathways for a residential receptor would include ingestion and dermal contact with groundwater.

FIGURE 3.1 Site Conceptual Exposure Model for the Groundwater Operable Unit at the Chemical Plant Area



[a] Other minor sources are wastewater treatment plants, laboratory building, Mechanical City, storage bunkers, regraining areas, lagoons, and dumps.
[b] Includes remaining sources of contamination after completion of the ongoing remediation.
[c] Includes sorbed contaminants in the vadose zone.
[d] Includes the sorbed contaminants within the shallow unconfined aquifer.
[e] Includes sediment within the conduit system.
[f] Includes surface water and sediment at Burgermeister Spring.
[g] No potential receptor; serves as transport medium to the surface water.
[h] Includes surface water at Burgermeister Spring; exposures to biota at Burgermeister Spring are included as part of the exposure model for the chemical plant area.
[i] A future resident is not considered to be a plausible scenario; calculations for this scenario will be included in the risk assessment for comparative purposes. Potential pathways for a residential receptor would include ingestion and dermal contact with groundwater.

FIGURE 3.2 Site Conceptual Exposure Model for the Groundwater Operable Unit at the Ordnance Works Area

For the ordnance works area, data collected between March 1989 and May 1994 have been used to evaluate potential site contaminants. Because background data have not yet been finalized, substances with levels below background have been identified but not eliminated from further consideration. Further comparison will be presented in the RIs after background data have been established via the joint sampling effort.

An initial screening evaluation was conducted to identify potential site contaminants for the GWOUs on the basis of human health concerns. The screening evaluation consisted of two steps: (1) comparison of maximum site concentrations with federal and state criteria; and (2) calculation of conservative health risks, by assuming reasonable worst-case intake levels of groundwater (see Sections 3.1.2.1 and 3.1.2.2). The results of the screening evaluation will be used to focus future investigations on substances that might cause adverse human health effects from exposure to groundwater; in addition, the joint sampling effort also included sampling for a few additional analytes requiring confirmatory data.

The following analytes did not exceed background concentrations: for the chemical plant area — antimony, arsenic, beryllium, cadmium, cobalt, and zinc; and for the ordnance works area — antimony, beryllium, cobalt, lead, selenium, and vanadium. For the ordnance works area, levels of beryllium, cobalt, and vanadium were not considered to be elevated, even though upper-end concentrations at the site were slightly higher than background concentrations in one well group; the upper-end concentrations were not considered to be elevated because professional judgment indicated that the differences were very unlikely to be significant (i.e., a value of 3.0 µg/L for beryllium in the weathered unfiltered group, compared with a 2.5-µg/L background; a value of 35 µg/L for cobalt in the weathered unfiltered group, compared with a 29-µg/L background; and a value of 17 µg/L for vanadium in the unweathered unfiltered group, compared with a 14-µg/L background).

Substances that did not exceed federal or state criteria (Tables 2.8 and 2.13) were generally not considered further as potential site contaminants because these substances would not present a human health concern. The substances that could be deleted from further consideration on the basis of comparison with federal and state criteria were as follows: for the chemical plant area — radium-226, radium-228, thorium-228, thorium-230, thorium-232, arsenic, barium, beryllium, copper, fluoride, silver, and zinc; and for the ordnance works area — barium, beryllium, copper, chloride, chromium, fluoride, silver, selenium, and zinc; however, substances that did not exceed criteria but consistently exceeded background concentrations were included in the joint sampling effort to obtain confirmatory data.

The health risk calculations conducted for the remaining contaminants assumed reasonable worst-case exposure conditions to avoid ruling out substances that should be evaluated further in a subsequent baseline risk assessment. These worst-case conditions include the use of constituent concentrations calculated as the average of detected concentrations (i.e., the large numbers of nondetected values were not included, thereby increasing the average) and the assumption of groundwater use by a residential receptor.

Identification of a substance as a potential site contaminant does not necessarily mean that more data are needed to evaluate the risks associated with the substance, but only that risks cannot be ruled out on the basis of the available data. Substances are also identified that are not considered potential site contaminants but that require limited further evaluation (e.g., more sampling results from specific wells). For Burgermeister Spring, substances that were ruled out as potential site contaminants on the basis of human health considerations may still require further evaluation with respect to ecological effects. The potential site contaminants for the chemical plant area, the ordnance works area, and Burgermeister Spring are summarized in Table 3.1.

TABLE 3.1 Potential Site Contaminants of Concern for Human Health[a]

Chemical Plant Area	*Ordnance Works Area*
Uranium	Nitroaromatics
Nitroaromatics	Antimony
Antimony	Arsenic
Cadmium	Cadmium
Chromium	Lead
Lead	Mercury
Lithium	Nickel
Mercury	Thallium
Molybdenum	Nitrate
Nickel	
Selenium	*Burgermeister Spring*
Sulfate	
Thallium	Uranium
Nitrate	Nitroaromatics
	Nitrate

[a] The potential site contaminants are those that are of concern with respect to human health considerations, either because of exceedance of state or federal criteria or because of results of preliminary risk calculations. Other analytes that require limited confirmatory sampling data because they exceed background levels or SMCLs include aluminum, barium, copper, iron, manganese, silver, chloride, and fluoride. These other analytes have been included in the joint sampling effort for all wells in the current monitoring network. For further confirmation, select volatile organic compounds (i.e., toluene in MWS 5 and carbon disulfide in MWS 104) were also sampled in one round of the joint sampling effort.

3.1.2.1 Radioactive Contaminants

Results of the data collected and analyzed at the chemical plant area indicate that uranium is the only potential radioactive site contaminant. Uranium has been consistently measured in several wells, in the Southeast Drainage, and in Burgermeister Spring at levels exceeding the drinking water criterion for total uranium. Data have also been collected to measure concentrations of other primary radionuclides associated with past processing activities at the chemical plant (i.e., thorium and radium isotopes). Sufficient data have been collected at consistently low levels to dismiss these radionuclides as potential site contaminants.

Because radioactive materials were not processed at the ordnance works area, data were not analyzed for radionuclides; however, results of one round of analysis indicated elevated levels of gross alpha and gross beta. It is expected that radioactive contamination, if it exists at the ordnance works area, would be similar to that found in groundwater at the chemical plant area (i.e., uranium). Confirmation of the absence or presence of radioactive contamination in groundwater beneath the ordnance works area will be determined from data collected as part of the joint DOE-CE sampling program (see Chapter 4).

3.1.2.2 Chemical Contaminants

In this section, potential site contaminants are discussed for the following areas and media: groundwater in the chemical plant area, groundwater in the ordnance works area, and surface water at Burgermeister Spring. The potential chemical site contaminants for each area are summarized in Table 3.1.

Groundwater in the Chemical Plant Area. Nitroaromatic compounds are considered potential site contaminants because of their association with past site processing activities and their presence in groundwater. The maximum concentrations of 2,4-DNT; 2,6-DNT; and 2,4,6-TNT exceed available EPA (1995) health advisory levels (Table 2.8).

The results of groundwater monitoring data indicate the presence of some metals and inorganic anions at levels exceeding background concentrations and primary drinking water criteria. These contaminants — antimony, cadmium, chromium, lead, mercury, nickel, selenium, sulfate, thallium, and nitrate — were identified as potential site contaminants; however, drinking water criteria for several of the metals (e.g., cadmium, chromium, and selenium) were only exceeded in a few samples from isolated wells.

For the remaining metals and anions (i.e., calcium, cobalt, iron, lithium, magnesium, manganese, molybdenum, potassium, sodium, vanadium, and chloride), a two-tiered, risk-based screening procedure was conducted. The first tier of this procedure was a comparison of levels of essential metals and anions with available recommended dietary allowances (RDAs) (National Research Council 1989). Intakes were estimated for infants (10 kg; 1-L/d water intake) and adults (70 kg; 2-L/d water intake). Intakes were based on the highest average concentration of each constituent in either the weathered or unweathered well group (see Tables 2.6 and 2.7). When higher, the maximum average from unfiltered samples was used, even though these sample sizes were very small; this approach was taken so that the potential risk would not be underestimated. A maximum of half of the RDA was assumed to be ingested in drinking water (this assumption allows for a dietary contribution to exposure). These calculations showed that calcium, potassium, sodium, and chloride intakes from groundwater would be less than half of the RDA, even under an unlikely future-resident exposure scenario. This result was considered sufficient justification to rule out these substances as potential site contaminants from the perspective of human health risk.

The second tier of the screening procedure was a comparison of intake levels (as calculated previously) with available EPA reference dose (RfD) values or with other estimates of safe intake levels when RfD values were not available. This comparison was conducted for cobalt, iron, lithium, magnesium, manganese, molybdenum, and vanadium. For cobalt, magnesium, and vanadium, the calculated hazard quotient based on half of the RfD or a comparable value (again allowing for dietary intake of the substances) was less than 1, indicating that use of the water as a drinking water source would be without adverse effects over a lifetime. These substances were therefore eliminated from further consideration. The screening procedure indicated potential health risks for lithium and molybdenum, so they were retained as potential site contaminants. Although the screening procedure also indicated potential health risks for iron and manganese, this result was likely due to the small sample size for unfiltered samples (i.e., the calculations were based on the mean concentrations from unfiltered samples from the unweathered well group [n = 5] for both substances). The results of the joint DOE-CE sampling program will be used to better characterize the levels of iron and manganese in unfiltered samples at the chemical plant area.

Aluminum, iron, and manganese were detected in many wells at levels exceeding SMCLs (criteria based on aesthetic water quality considerations, rather than on adverse health effects). No health-risk-based screening criterion was identified for aluminum, so it was not included in the screening procedure. Because these substances exceeded secondary drinking water criteria, the substances were identified as requiring further evaluation.

Designation of a substance as a potential site contaminant may or may not indicate a need for further data collection because sizable amounts of data already exist. Additional data requirements for potential site contaminants and selected other constituents are identified in Section 3.5. Designation of a potential site contaminant indicates a need for more in-depth analysis in future RI work of potential human health risks associated with the substance.

Groundwater in the Ordnance Works Area. Nitroaromatic compounds are considered potential site contaminants because of their association with past site processing activities and their presence in groundwater. Of the four nitroaromatics with available health advisory levels — 1,3-DNB; 2,4-DNT; 2,6-DNT; and 2,4,6-TNT — all have been measured in groundwater at concentrations exceeding the health advisory levels (see Table 2.13).

Available data indicate the presence of antimony, arsenic, cadmium, lead, mercury, nickel, thallium, and nitrate at levels exceeding background concentrations and primary drinking water criteria. These substances were identified as potential site contaminants.

Arsenic was detected at a maximum concentration of 430 µg/L in an unfiltered sample from MWS 8 but was either not detected or measured at less than 12 µg/L in seven other sampling rounds; however, arsenic was also detected at concentrations exceeding the MCL of 50 µg/L in five of eight unfiltered samples (range, 52 to 234 µg/L) from well MWS 103, indicating a possible isolated source of contamination near this well.

Mercury was identified as a potential site contaminant because of its presence in filtered and unfiltered samples from well MWGS 2 at concentrations of 5.5 and 7.7 µg/L, respectively, compared with the MCL of 2 µg/L. (Additional data are not available for this monitoring well.) Mercury was also detected at levels above the MCL in single samples collected from wells MWS 14 and MWS 105; these elevated levels were not substantiated by other samples from these wells.

Nickel was identified as a potential site contaminant primarily because of consistent concentrations in filtered and unfiltered samples from MWS 21, ranging from 110 to 204 µg/L, which exceed the MCL of 100 µg/L. Nickel was also detected at levels above the MCL in six other wells; the elevated levels in these wells were not substantiated by data from other sampling rounds.

Nitrate was detected in MWS 11 at a concentration of 16 mg/L, which exceeds the MCL of 10 mg/L. Although samples from the other wells did not exceed the MCL, nitrate was retained as a potential site contaminant on the basis of the one exceedance.

Beryllium and selenium were both below background concentrations and health criteria, so these substances were not considered further. For the remaining metals and anions (i.e., calcium, cobalt, iron, magnesium, manganese, potassium, sodium, and vanadium), the two-tiered, risk-based screening procedure described previously for the chemical plant area was conducted. The same intake assumptions, RDA values, and RfD values were used for comparisons. The highest average concentration of each constituent from filtered or unfiltered samples — including samples from the weathered, unweathered, USGS, and deep well groups — was used in the calculations (see Tables 2.11 and 2.12). For the ordnance works area, intake of the following substances was found to be less than half of the RDA value in the first tier of the screening process: calcium, manganese, potassium, and sodium. These substances were eliminated from further consideration as potential site contaminants from the perspective of human health risk.

By using RfD or comparable values, intakes of cobalt, magnesium, and vanadium were found to be less than half of the RfD levels in the second tier of screening. Health impacts from iron could not be ruled out and may require further evaluation.

Aluminum, iron, and manganese were detected in many wells at levels exceeding SMCLs. For manganese, adverse health effects are not expected to be associated with water consumption on the basis of the screening procedure described previously. Although sulfate was detected in some wells at levels exceeding the SMCL, no samples exceeded the MCL value of 500 mg/L. No health-risk-based screening criterion was identified for aluminum. Because these substances exceeded secondary drinking water criteria, the substances are identified as requiring further evaluation.

Burgermeister Spring. Nitroaromatic compounds have been detected at Burgermeister Spring and have been retained as potential site contaminants. Of the metals and inorganic anions, nitrate was detected at levels exceeding the primary drinking water criteria and was identified as a potential site contaminant. Manganese exceeded the SMCL and was therefore retained for further evaluation; however, manganese does not constitute a human health hazard at the levels detected.

3.1.3 Potential Release and Transport Mechanisms

Three primary release mechanisms have been identified for the conceptual models of the two GWOUs: dissolution, desorption, and suspension. Release mechanisms and environmental transport pathways for the current sources identified in Section 3.1.1 are discussed in Sections 3.1.3.1 through 3.1.3.3.

3.1.3.1 Residual Contamination in the Vadose Zone

In the vadose zone, contamination can be released and mobilized through the combined actions of dissolution of particulate contaminants and desorption of contaminants from subsurface particles (Figures 3.1 and 3.2). These mechanisms would be driven primarily by infiltration and precipitation. The greatest rates of dissolution and desorption would occur for those contaminants having the largest solubilities and the smallest distribution coefficients (K_d values). Once mobilized, the contaminants would be transported downward by gravity toward the water table, where contamination of the shallow groundwater system could occur.

3.1.3.2 Contaminated Rock and Residuum in the Phreatic Zone

Desorption is the primary release mechanism for contaminated saturated bedrock and residuum, although some additional mobilization could occur by dissolution of any particulate contaminants in the phreatic zone. Because of the relatively low hydraulic conductivity, the low velocities, and the small pore sizes of the saturated porous medium, direct transport of contaminated particles is not possible. The desorbed contaminants could contaminate the groundwater and be transported by the natural hydraulic gradient. North of the groundwater divide, contaminants would move to the north; south of the divide, the contaminants would be transported toward the Missouri River. To the north of the chemical plant area, contaminants could enter into the subsurface conduit that discharges to Burgermeister Spring near Lake 34. Sorbed contamination in the phreatic zone could thus produce additional groundwater contamination, as well as contamination of nearby surface water.

3.1.3.3 Sediment in the Conduit System

The last source of current contamination is sediment in the conduit system located in the ordnance works area, including sediment in the conduit to Burgermeister Spring. Sediment in the Southeast Drainage is being addressed as a separate action. Contaminated sediment in the conduit system is believed to have resulted from infiltration of contaminated materials from contaminated surface locations associated with former Army activities (e.g., burning grounds, lagoons, bunkers, and wastewater treatment plants) and from groundwater and surface water runoff that has been contaminated from historical sources at the chemical plant area. Contaminants in the sediment can be released and mobilized by suspension in flowing water and be dissolved, desorbed, and transported by infiltration and percolation of precipitation and ponded water. Depending on the dynamics of the system (in particular, the points of discharge), both surface water and groundwater could be contaminated by these sources.

3.1.4 Potential Human Receptors and Routes of Exposure

Exposure points are defined as points of potential contact of a receptor with a contaminated source or environmental medium. The contaminated sources associated with the GWOUs include contaminated material in the vadose zone, contaminated rock and residuum in the phreatic zone, and contaminated sediment and surface water in the conduit system. The contaminated media associated with the operable units are surface water and groundwater. Surface water includes discharges to Burgermeister Spring in the August A. Busch Memorial Conservation Area to the northwest of the chemical plant area. Likely human activities under current and potential future land-use conditions were considered in identifying the potential human receptors for the GWOUs. The routes of exposure identify the means by which the contaminants can be taken in by a receptor. For this assessment, external gamma irradiation, ingestion, and dermal contact were considered to be potential exposure routes. Inhalation from water sources is not considered because the potential site contaminants are not volatile.

3.1.4.1 Groundwater

Groundwater occurs in three principal bedrock aquifer systems: (1) a shallow aquifer that is primarily unconfined and consists of saturated rocks of the Burlington-Keokuk Limestone and Fern Glen Formation; (2) a middle confined aquifer composed of the Kimmswick Limestone; and (3) a deep confined aquifer that consists of the St. Peter

Sandstone through the Potosi Dolomite. In addition, an unconfined alluvial aquifer exists near the Missouri River. The groundwater system of interest is the shallow bedrock aquifer system. Monitoring and characterization data indicate that most of the contamination exists in the weathered portion of the Burlington-Keokuk Limestone. Because DOE and the Army maintain ownership of the sites, groundwater is restricted from public use. Therefore, a point of human contact with the contaminated medium (i.e., a complete exposure pathway) does not exist under the current land-use scenario.

Under future land use, groundwater is unlikely to be used by the public. The Army expects to retain ownership of the training area and to continue using this property for training activities. At the chemical plant area, a disposal cell is being built on-site that will occupy much of the total area. Although residential use of either site is unlikely, calculations for a hypothetical future-resident scenario will be included in the risk assessment for comparative purposes. Calculations will be performed for a resident using water from the shallow groundwater system. To be conservative, the assumption was made that only the shallow groundwater system would be used as a source of water. The potential routes of exposure for this receptor include ingestion and dermal contact.

3.1.4.2 Burgermeister Spring

Burgermeister Spring is located northwest of the chemical plant area in the August A. Busch Memorial Conservation Area (Figure 2.1). Under current conditions, land use is recreational, and the most likely receptor is a recreational visitor. Future land use is expected to remain recreational, so the most likely future receptor would also be a recreational visitor. The potential exposure routes for this receptor are ingestion of and dermal contact with surface water. Because the spring is small, the potential for dermal contact with and incidental ingestion of sediment would be low and is not likely to be a significant route of exposure. External gamma irradiation is not an issue for this spring because of the water cover and the low levels of uranium measured in the sediment.

3.1.5 Potential Ecological Receptors and Routes of Exposure

The principal exposure route for ecological resources of the area is the surface water that receives contaminated groundwater drainage, namely Burgermeister Spring and the Southeast Drainage. Because of the nature, form, and type of the contamination associated with these areas, the principal ecological receptors are those species associated with the aquatic habitats at, and influenced by, the spring and drainage; terrestrial receptors and pathways are of less concern; however, several terrestrial species (e.g., white-tailed deer) use streams, ponds, and lakes as sources of water. Each exposure route is a function of the type of habitat (e.g., aquatic or terrestrial), biotic factors (such as the behavior, feeding strategy, and reproductive requirements of the receptor species), and abiotic factors (such as the form of the contaminated media, the characteristics of each contaminant, and geochemical conditions).

At Burgermeister Spring and the Southeast Drainage, exposure of biota to contaminants would be primarily through contact with contaminated surface water or sediment (or both). Uptake of contaminants could occur via (1) direct contact with contaminated water or sediment (or both) and subsequent uptake across surface membranes (absorption) and (2) ingestion of contaminated water or sediment during intake of food or water. Absorption of contaminants across body surfaces represents a major pathway of contaminant entry into aquatic biota, with gill membranes representing a particularly important site of contaminant uptake (Boudou and Ribeyre 1989). Additional pathways to ecological receptors that do not come into direct contact with contaminated media can occur by transport through the food chain. The exposure, uptake, and transport of contaminants from water and sediment into aquatic biota and through the aquatic food chain is shown in Figure 3.3 (individual receptors are federal- or state-listed species; some pathways are more important than others).

Exposure of biota to groundwater contamination would primarily affect deep-rooted plants. Exposure to contaminated surface water following groundwater discharge to the surface water could affect a variety of aquatic organisms, including fish, amphibians, reptiles, and aquatic macroinvertebrates. Terrestrial species could also be exposed by drinking or contacting contaminated water or by preying on aquatic biota. Exposure to contaminated sediments could impact burrowing aquatic organisms, benthic fish (e.g., darters), and amphibians that use the sediment-water interface of aquatic habitats. In addition, contaminated sediment and surface water might also affect the eggs, embryos, and fry of aquatic macroinvertebrates, fish, and amphibians.

Site-specific data are available for several biotic groups at Burgermeister Spring and the Southeast Drainage (Environmental Science and Engineering 1993; MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992d, 1993). Thus, some species can be identified as potential receptors, including federal- and state-listed species; these receptors are listed in Table 3.2. None of the federal- or state-listed species that have been reported from the chemical plant area (Section 2.3.4) are known to be directly threatened by site contamination.

Discharge of contaminated water and sediment from the Southeast Drainage to the Missouri River could, via food chain transfer or direct uptake (or both), affect the paddlefish (C2), the sicklefin and sturgeon chubs (both C2), and the pallid sturgeon (federal endangered). These species have been reported from the Missouri River in the vicinity of the Southeast Drainage confluence (DOE 1992a; Reitinger 1994) but are restricted to large rivers and would not be expected to enter the Southeast Drainage or to occur at Burgermeister Spring.

The bald eagle (federal endangered) is a seasonal visitor to Howell Island and might forage in the Missouri River in the vicinity of the Southeast Drainage or might occasionally feed on fish from Lake 34 and thus be exposed to contaminants from Burgermeister Spring via food chain transfer. The federal endangered least tern and peregrine falcon are transient visitors to the Busch Conservation Complex, so the potential for contaminant exposure of these species is very limited.

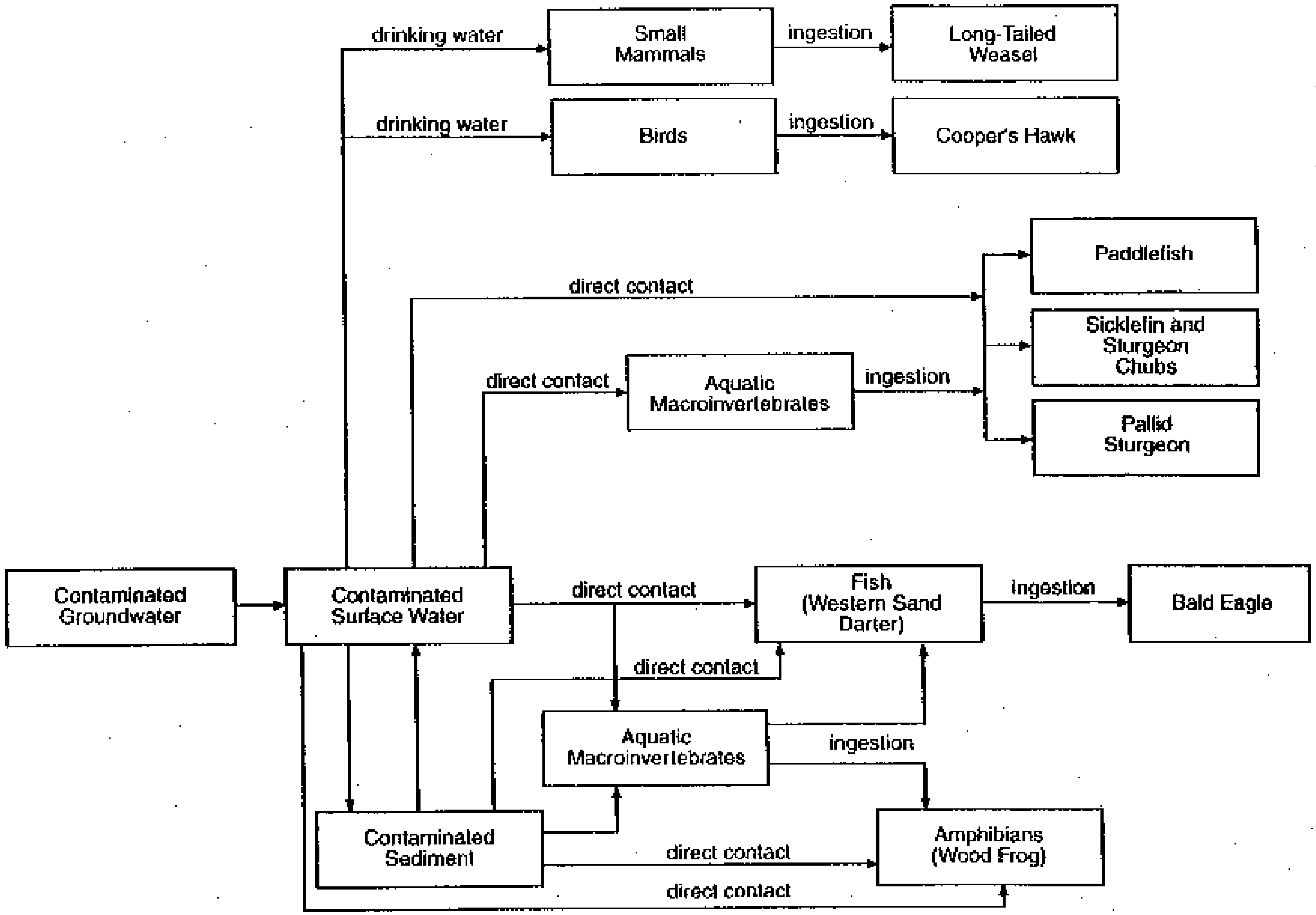


FIGURE 3.3 Conceptual Model of Contaminant Exposure, Uptake, and Transfer through Biotic Pathways at Burgermeister Spring and the Southeast Drainage

TABLE 3.2 Preliminary Ecological Receptors at Burgermeister Spring and the Southeast Drainage and Principal Exposure Routes[a]

	Principal Exposure Routes	
Taxon	Burgermeister Spring	Southeast Drainage
Macroinvertebrates		
Gammarus sp.	Exposure to water and sediment; food uptake	Exposure to sediment and water; food uptake
Caecidotea sp.	Exposure to water and sediment; food uptake	Exposure to sediment and water; food uptake
Chironomid larvae (*Microspectra* sp. and *Microtendipes* sp.)	Exposure to water and sediment; food uptake	Exposure to sediment and water; food uptake
Fish		
Western sand darter	Exposure to water and sediment; food uptake	Exposure in the Southeast Drainage to water and sediment; food uptake
Paddlefish	Not applicable	Exposure in the Missouri River to water and sediment; food uptake
Sicklefin chub	Not applicable	Exposure in the Missouri River to water and sediment; food uptake
Sturgeon chub	Not applicable	Exposure in the Missouri River to water and sediment; food uptake
Pallid sturgeon	Not applicable	Exposure in the Missouri River to water and sediment; food uptake
Amphibians		
Pickerel frog	Not applicable	Exposure to water and sediment; food uptake
Wood frog	Not applicable	Exposure to water and sediment; food uptake
Birds		
Bald eagle	Food uptake; incidental ingestion of water	Food uptake; incidental ingestion of water
Mammals		
Long-tailed weasel	Food uptake	Food uptake

[a] Additional receptors will be identified following completion of biotic surveys for macroinvertebrates, fish, amphibians, and reptiles.

The western sand darter (state watch listed) has been reported from St. Charles County (Gaines 1988), and suitable habitat is present for this species at Burgermeister Spring and within the lower reaches of the Southeast Drainage. The Cooper's hawk (state endangered) and the long-tailed weasel (state rare) occur in the Weldon Spring Conservation Area and might be exposed to contaminants through food chain transfer. The wood frog (state rare) occurs in the conservation complex and might inhabit the forest areas along the Southeast Drainage. No suitable habitat for this species exists along the Burgermeister Spring drainage.

3.2 TOXICOLOGICAL AND ENVIRONMENTAL PROPERTIES OF SELECTED CONTAMINANTS

As background information for this work plan, the toxicological effects associated with potential radiation exposure and the major toxicological effects of selected potential chemical contaminants associated with the GWOUs are described in Sections 3.2.1 and 3.2.2. For most of the contaminants identified, the potential is greater for chronic (long-term) than for acute (short-term) effects on humans and biota under current conditions.

3.2.1 Radiation Toxicity

3.2.1.1 Human Health

Radiation health effects for humans have been confirmed only at relatively high doses or at high dose rates with large populations. Hence, risk estimates are strictly applicable only to large populations because the appearance of health effects after an exposure is a chance event. For low doses, health effects are presumed to occur but can only be estimated statistically. These effects cannot be predicted with certainty for small populations (e.g., a few individuals).

Radiological health effects can be expressed as the increased likelihood of cancer induction for an exposed individual or population; however, risk estimates are uncertain for the low dose range because of the necessary extrapolation of effects from high doses and because of assumptions regarding the dose-response relationships and the underlying mechanisms of radiation-induced carcinogenesis. In fact, studies of populations chronically exposed to low-level radiation (e.g., in regions of elevated natural background radiation) have not shown consistently conclusive evidence of an associated higher risk of cancer induction.

Uranium has been identified as a potential site contaminant for the GWOU of the chemical plant area. Natural uranium consists of three isotopes: uranium-234, uranium-235, and uranium-238. Two hazards associated with uranium compounds are kidney damage caused by the chemical toxicity and cell damage caused by the ionizing radiation that results from radioactive decay. Alpha particles and gamma rays are emitted from the decay of uranium. Alpha particles are primarily a hazard when taken into the body (e.g., by ingestion or inhalation) because, for external exposures, alpha particles cannot penetrate the outer layer of dead skin cells. When uranium enters the body, only a small fraction is absorbed into the bloodstream; the majority is excreted. Within the body, alpha particles result in greater cell damage than beta or gamma radiation because their energy is completely absorbed by the tissue. Gamma radiation is primarily an external hazard because it can easily penetrate tissue and reach internal organs; however, external radiation is generally not a concern because uranium emits only a small amount of penetrating energy at relatively low energies.

3.2.1.2 Biota

Identifying the effects of radionuclides on organisms in the natural environment is complicated, and describing effects has been largely confined to laboratory situations, which are not necessarily relevant to situations such as remediation of the GWOUs considered here. These complications in the natural environment arise because (1) various sources of ionizing radiation are possible; (2) exposure can be internal, external, or both; (3) each radionuclide has unique physical and chemical properties; (4) ecological receptors have different mobilities and varied habitats; and (5) current levels of radionuclides in most areas are too low to detect effects on the population and community, even in such areas as weapons testing sites (Whicker and Schultz 1982a-b).

For nonhuman biota, the induction of damage to biological tissues from each type of radiation (alpha, beta, and gamma) and the exposure pathways are similar to those for human receptors. Radiation exposure of ecological receptors has been reported to cause a wide variety of biological responses, including lethal and sublethal developmental and behavioral changes, reduced survival, and teratogenic and genetic changes (Rose 1992).

3.2.2 Chemical Toxicity

3.2.2.1 Human Health

On the basis of available information, potential site contaminants identified for the GWOUs include metals, inorganic anions, and nitroaromatics. Metal compounds form complexes with inorganic species or organic ligands present in the environment. The speciation of a metal in a given environment affects its bioavailability, solubility, volatility, and sorptive properties. In addition to speciation, the fate of metals is affected by the properties of the environmental media; for example, properties affecting the mobility of a metal in water depend on the presence of other chemical species, the pH, the oxidation-reduction potential (E_h), and the temperature.

Of the metals identified in the various media investigated to date, certain compounds of lead are carcinogenic and may induce teratogenic and other adverse reproductive effects. The health hazards associated with nitrates result primarily from the bacterial conversion of ingested nitrates to nitrites, which can result in methemoglobinemia (i.e., reduction in the oxygen-carrying capacity of blood), especially in infants.

Nitroaromatic compounds have been detected in groundwater from the two GWOUs. These compounds have also been shown to induce methemoglobinemia. Other effects include toxic effects on the liver, kidneys, and nervous system. Studies in humans indicate that nitroaromatic compounds are absorbed following inhalation and ingestion and that these compounds are capable of penetrating the skin.

Further information on the toxicity of the potential site contaminants for the two GWOUs is provided in Section 4.4 of the BA for the chemical plant area (DOE 1992a).

3.2.2.2 Biota

The principal chemotoxic contaminants of ecological concern include arsenic, chromium, lead, mercury, selenium, silver, uranium, nitrate, and nitroaromatics in Burgermeister Spring and chromium, copper, lead, manganese, silver, zinc, uranium, nitrate, and nitroaromatics in the Southeast Drainage. The toxicity of these contaminants varies among biotic species and depends on physical and chemical factors such as pH and the presence of complexing agents. Additional potential site contaminants may be identified following further contaminant characterization activities at Burgermeister Spring and the Southeast Drainage and after toxicity reference values and maximum allowable tissue concentrations are developed for the ecological receptors during the baseline risk assessment.

Metals have been reported to cause a wide variety of lethal and sublethal effects in aquatic and terrestrial biota. In vegetation, adverse effects from exposure to metals include reduced chlorophyll concentrations, reduced growth, and reduced seed production and germination. In aquatic biota, metal exposure has been shown to affect reproduction, ion exchange across gill surfaces, and survival of all life stages and to cause behavioral changes in higher species. In terrestrial biota, metal exposure may result in limb deformities, stunting, skin ulcerations, kidney and central nervous system damage, altered blood chemistry, altered metabolic processes, and changes in foraging and other behaviors. Exposure of wildlife to high concentrations of nitrate may result in reduced oxygen binding of hemoglobin, altered cardiac activity, muscle atrophy, reduced growth, and disruption of metabolic processes such as glycolysis and the pentose phosphate cycle.

The available literature regarding the movement, concentration, and effects of the chemical contaminants on biota is sparse for many of the potential site contaminants. Several of the ecological contaminants of concern have been detected at Burgermeister Spring and the Southeast Drainage at concentrations reported to cause a range of adverse effects at sublethal concentrations. Although several potential site contaminants were not detected in surface water or sediment from the spring, the detection limits of the analytical techniques used for some of the contaminant characterization activities were greater than either the EPA AWQC for protection of aquatic biota (EPA 1986) or the concentrations reported in the scientific literature to result in adverse effects to biota. Furthermore, to what extent synergistic or antagonistic interactions are co-occurring among the contaminants is not known. Such interactions may result in greater or less toxicity than would be expected.

3.2.2.3 Fate and Transport

Potential site contaminants for the GWOUs at the Weldon Spring site include metals (arsenic, antimony, cadmium, chromium, lead, lithium, mercury, molybdenum, nickel, selenium, thallium, and uranium), inorganic anions (nitrate), and nitroaromatic compounds (1,3-DNB; 2,4-DNT; 2,6-DNT; NB; 1,3,5-TNB; and 2,4,6-TNT). The fate and transport of these substances through the groundwater system depends on the mobility and persistence of the contaminants. The following sections provide brief discussions on the fate and transport for the major groups identified previously; additional details are presented in the BA for the chemical plant area (DOE 1992a).

Metals. Adsorption and precipitation and, to a lesser extent, coprecipitation are expected to play a major role in attenuating metal concentrations in the groundwater at the Weldon Spring site. Geochemical investigations conducted by the USGS indicate that uranium and other metals readily sorb to the overburden material, thus limiting their transport to the underlying groundwater system. Once in the groundwater, metals have a very long persistence; they do not easily degrade (arsenic and mercury can be microbially methylated and volatilized; however, they are subsequently converted back to inorganic forms as part of the natural environmental cycling process [DOE 1992a]). Because of sorption, metals are not expected to migrate substantially away from their point of origin. Of the metals listed previously, lithium and arsenic would be the most mobile; their distribution coefficients (K_d values) are estimated to be about 9 mL/g (Schumacher and Stollenwerk 1991) and 10 mL/g (Baes and Sharp 1983), respectively. The distribution coefficients for the other metals included in the list of potential site contaminants are all higher; for example, the K_d values for lead and uranium are estimated to be 150 and 330 mL/g, respectively (Schumacher and Stollenwerk 1991), and their mobilities would be correspondingly smaller. For more details on the best-estimate distribution coefficients for the metals of concern, see Table E.1 of the BA (DOE 1992a).

Inorganic Anions. Unlike the metals, nitrate is highly mobile and has a distribution coefficient of less than about 1 mL/g (DOE 1992a). This contaminant will therefore be highly mobile in the groundwater system. In addition, nitrate is very persistent in the environment and does not readily degrade (DOE 1992a).

Nitroaromatics. Nitroaromatic compounds readily undergo photodegradation (e.g., to TNB) and biotransformation. At Weldon Spring, native microbial populations biodegrade TNT; 2,4-DNT; and 2,6-DNT to aminonitro intermediates (e.g., 4-amino-2,6-DNT and 2-amino-4,6-DNT) within 20 to 60 days (Bradley et al. 1994a-c).

Nitroaromatics have low persistence and relatively low solubilities, but their mobilities are high because of low distribution coefficients (e.g., the K_d value for TNT is about 0.28 mL/g for a site-specific fraction of organic carbon in the soil of 1.4% [DOE 1992a; McKone 1990]). Although large concentrations of TNT have been detected in surficial materials at the Weldon Spring training area, concentrations generally decrease to less than the detection limit (1 mg/kg) at depths greater than about 5 ft below the land surface (Schumacher et al. 1992). Concentrations of TNB ranging from less than 3 to 1,130 µg/L have also been detected with lysimeters. The data indicate decomposition of TNT to 4-amino-2,6-DNT and 2-amino-4,6-DNT within the upper unsaturated soil and photolysis of TNT to TNB at the surface; the degradation products are subsequently transported within the soil and shallow groundwater system.

3.3 PRELIMINARY RESPONSE OBJECTIVES AND TECHNOLOGIES

The overall objectives of the final response actions for the two GWOUs are to

- Protect human health and the environment in both the short and long term by developing a permanent solution that addresses the radioactive and chemical contaminants of concern in the affected media and limits related exposures;
- Implement the actions in a manner that will minimize contaminant transport to unaffected areas and attain compliance with relevant and appropriate environmental requirements; and
- Release the property for unrestricted use, to the extent practicable.

The affected media of the two GWOUs include groundwater, contaminated material in the saturated and unsaturated zones (i.e., sediment and bedrock), surface water and sediment at Burgermeister Spring and in the conduit system, and surface water in the Southeast Drainage. Response objectives for the two GWOUs can be identified on the basis of (1) complying with available regulatory standards and guidelines and (2) limiting potential exposures and risks. Key environmental regulations that will be considered relative to compliance are identified in Section 3.5. General risk-based objectives that encompass each of these media are as follows:

- Exposures to radionuclides should be reduced to levels as far below health-based criteria as can reasonably be achieved, as limited by the natural presence of radionuclides in the given media.
- Exposures to carcinogenic chemicals should not result in a total incremental lifetime risk to an individual of more than 1×10^{-6} to 1×10^{-4}, as limited by the natural presence of chemicals in the given media.

- Exposures to noncarcinogenic chemicals should not result in significant adverse health effects to an individual, indicated by a hazard index greater than 1, as limited by the natural presence of chemicals in the given media. (A hazard index addresses noncarcinogenic health effects from exposures to multiple contaminants; however, because the effects of the chemicals of concern may not be additive [i.e., they may affect different organ systems], a segregated hazard index may also be used to clarify the likely magnitude of effects for individual organ systems.)

- Exposures of biota should be limited to levels that are not associated with significant adverse ecological effects, considering available criteria and experimental and field data, as limited by the natural presence of radionuclides and chemicals in the given media.

The methodology and assumptions that have been used to estimate cancer risks, noncarcinogenic effects, and the potential for adverse ecological effects associated with contaminants at the sites are described in detail in the BA for the chemical plant area (DOE 1992a) and in the baseline risk assessment for the ordnance works (IT Corporation 1993g). Similar discussions will be provided in the baseline risk assessments to be prepared within the next several years for the two GWOUs to support the evaluation of cleanup objectives and appropriate response actions.

In developing responses for a contaminated site, six broad actions could be applied to each affected medium — either singly or in combination — depending on the scope of the action and the nature of the contamination problem. These six response actions are institutional controls, in situ containment, removal, treatment, short-term storage, and disposal. The treatment, storage, and disposal of all wastes resulting from cleanup actions for both sites have been addressed in previous documentation; any contaminated material removed from the two GWOUs under future response actions would be handled in the same manner as that described for similar material associated with those other actions at the chemical plant area and the ordnance works area (DOE 1992a-d, 1993b; IT Corporation 1993f-g; U.S. Department of the Army 1993). Therefore, the development of alternatives for the two GWOUs focuses on possible institutional controls, in situ containment, and treatment and removal actions. The general response actions and the types of technologies that could be applied to achieve the overall objectives are listed in Table 3.3. (See also Appendix B and Chapter 3 of the FS for the chemical plant area [DOE 1992b].)

The general objectives, response actions, and technologies that have been identified for the various contaminated media included in the two GWOUs at this stage of the evaluation process provide the building blocks for developing conceptual alternatives for the GWOUs. Preliminary alternatives are discussed in Section 3.4. Performance reliability and the expected permanence of the various response technologies as applied to conditions of the GWOUs are important factors that will be evaluated as part of the ongoing RI/FS process for this action. Criteria prescribed in the NCP will be used to evaluate the appropriateness of the technologies; these criteria will be presented in the FSs for the two GWOUs to be prepared within the next several years.

TABLE 3.3 General Response Actions and Technologies

General Response Action/ Technology Type	Affected Media	Comment
No action		
Not applicable	All	Provides a baseline for comparison with action alternatives
Institutional control		
Ownership and use of deed restrictions	All	Minimizes exposures to contaminants by prohibiting use of groundwater in affected areas
Monitoring	All	Provides data useful for assessing and minimizing exposures
Removal		
Excavation	Sediment	Removes contaminants; reduces exposures
Extraction (pump and treat)	Groundwater	Removes contaminated groundwater; reduces exposures
Interception	Groundwater	Removes contaminated groundwater; reduces exposures
Physical extraction	Surface water	Removes contaminants from surface water; reduces exposures
In situ treatment		
Chemical extraction/ flushing	Contaminated material in unsaturated and saturated zones; sediment	Reduces mobility and toxicity; reduces exposures
Chemical addition/ detoxification	Contaminated material in unsaturated and saturated zones; sediment	Reduces mobility and toxicity; reduces exposures
Chemical injection/ contact reaction	Contaminated material in unsaturated and saturated zones; groundwater	Reduces mobility and toxicity; reduces exposures
Biodegradation	Contaminated material in unsaturated and saturated zones; sediment; surface water; groundwater	Reduces mobility, volume, and toxicity; reduces exposures

3.4 CONCEPTUAL REMEDIAL ACTION ALTERNATIVES

The EPA has established a general framework for developing remedial action alternatives that is appropriate to the specific conditions at an NPL site (EPA 1988, 1990a). The scope, characteristics, and complexity of an individual operable unit or site constitute the case-specific framework from which to develop a preliminary list of alternatives that would be protective of human health and the environment. This protection can be achieved by eliminating, reducing, or controlling the risks posed by each exposure pathway associated with the operable unit or site. Alternatives are assembled by combining general responses and identifying basic technologies that could be appropriate for each contaminated medium to be addressed by the action.

Two major categories of response are typically considered in developing these alternatives for a contaminated site:

- Containment — involving little or no treatment but protective of human health and the environment by preventing or controlling exposures to contaminants through engineering measures and by using institutional controls as necessary to ensure the continued effectiveness of a response; and

- Treatment — ranging from alternatives that use treatment as the primary element of the response to address the principal threats posed by a site (this alternative may not involve the highest degree of treatment or the treatment of all waste) to alternatives that use treatment to reduce the toxicity, mobility, or volume of contaminated material to the maximum extent feasible, minimizing the need for long-term management.

As stated in Section 121(b) of CERCLA, as amended, the alternatives most preferred by the EPA for NPL sites are those that represent permanent and cost-effective solutions for protecting human health and the environment; those that permanently and significantly reduce the toxicity, mobility, or volume of contaminated material; and those that apply alternative treatment or resource recovery technologies to the extent possible. Least preferred are those alternatives involving the transport and disposal of waste off-site without treatment. A no-action or no-further-action alternative is also included to provide a baseline for comparison with other alternatives. For this alternative, response actions for which decisions have already been finalized are assumed to have been completed (e.g., the raffinate pits at the chemical plant area have been dewatered, and soil at both sites has been remediated).

The conceptual alternatives identified in this work plan represent a general classification of possible activities for response actions for the two GWOUs. These alternatives are based on the current understanding of the important exposure routes and receptors in the area. The alternatives will be refined as the RI/FS process proceeds. The purpose of identifying potential alternatives at this early stage of the process is to help ensure that appropriate data are collected to support the subsequent analyses of candidate technologies and alternatives. The potential alternatives are as follows:

- Alternative 1 — No action.
- Alternative 2 — Institutional controls and monitoring would be implemented for groundwater associated with the two operable units.
- Alternative 3 — Intrinsic bioremediation monitoring would be implemented for groundwater associated with the two operable units.
- Alternative 4 — Identified sources of sediment contamination would be remediated to the extent possible, and groundwater would be remediated to the extent possible by using a pump-and-treat technology.
- Alternative 5 — Identified sources of sediment contamination would be remediated to the extent possible, as for alternative 4; and groundwater would be remediated to the extent possible by using other available technologies.
- Alternative 6 — Identified sources of sediment contamination would be remediated to the extent possible, as for alternative 4; and groundwater would be remediated to the extent possible by using chemical or biological in situ treatment.

The most likely alternative for both GWOUs is a combination of alternatives 1 and 2 (i.e., no action, with institutional controls and monitoring). Alternative 3 involves natural attenuation with biodegradation of contaminants. Any alternative that treats the affected groundwater (alternatives 4, 5, and 6) is unlikely to be successful because of the nature of the contamination (widespread, with low levels of contaminant concentrations) and the adverse characteristics of the affected environment, including low conductivity, low sustained pumping yields, and superimposed fractures and weathering (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1990a).

This preliminary list of alternatives will be refined as additional data are collected and as further analyses are performed to support the evaluation of a final response for the two GWOUs. A refined list will be presented and analyzed in the FSs for the GWOUs.

3.5 DATA REQUIREMENTS

Data requirements have been identified in this work plan on the basis of the data evaluation (Section 2.4) and the discussion regarding the site conceptual exposure models (Section 3.1). These data include those needed to (1) verify the understanding of the hydrogeological conditions in a few specific areas; (2) further characterize the nature and extent of contamination in groundwater and at selected springs; (3) establish background groundwater concentrations of uranium, and further evaluate background groundwater concentrations of naturally occurring inorganic parameters (metals and anions); (4) confirm the potential site contaminants; and (5) further characterize ecological conditions at Burgermeister Spring and the Southeast Drainage (including determination of the occurrence of state-listed species and confirmation of the toxicity of surface water and sediment) in support of the ecological risk assessment included in the baseline risk assessment. Details regarding specific sampling activities are presented in Chapter 4.

3.5.1 Hydrogeological Characterization

Additional data are needed to further define potential pathways for contaminant migration within the shallow unconfined aquifer in support of the hydrogeological conceptual model (discussed in Section 2.3.3.2) and the selection of remedial alternatives. The following hydrogeological data requirements have been identified:

- Additional data from three angled boreholes are required to characterize transmissivity of the shallow aquifer in the northern and western parts of the chemical plant area, where geological information and results of previous aquifer tests indicate high values of hydraulic conductivity. Tracer tests and packer tests will be conducted at these boreholes to determine aquifer properties. The packer tests will be used to determine such properties as hydraulic conductivity and storativity. The tracer tests will be used to determine if this section of the chemical plant area is directly connected with the conduit system that discharges at Burgermeister Spring (because the Burgermeister Spring area appears to be a major groundwater drainage area).

- To further define the groundwater flow directions in a few specific regions at the ordnance works area, data will be collected from six newly installed wells, open to either the weathered or unweathered units of the Burlington-Keokuk Limestone, and from one retrofitted well. The locations for the new wells coincide with areas in which no Burlington-Keokuk wells are open to the weathered unit or in which the vertical gradient is not known. Information from these wells will be used to reduce subjectivity in the interpretation of the contoured surface for the shallow Burlington-Keokuk aquifer and to determine vertical gradients between the weathered and unweathered units of the Burlington-Keokuk aquifer system. Water levels will be measured to determine hydraulic gradients, and packer tests will be conducted to characterize aquifer properties. The proposed wells are located near existing wells or in pairs, resulting in well clusters, as follows:

    - Two wells (i.e., one well cluster) at the eastern part of the training area and adjacent to the chemical plant area (between MW-4005 and MWS 8);

- One well in the southern part of the training area (clustered with MWS 5);

- One well in the western part of the training area (clustered with MWS 23);

- One well north of the training area (clustered with MWS 107);

- One well northeast of the training area (clustered with USGS 7); and

- USGS 7, which is sampled by CE and will be retrofitted to develop a cluster with a new well.

• To provide additional information on aquifer properties (e.g., hydraulic conductivity), aquifer characterization data (i.e., slug tests) will be collected from existing wells at the chemical plant area and training area that have not been previously tested.

As indicated previously, the hydrogeological data requirements identified are primarily concerned with improving the understanding of the groundwater flow system in the Burlington-Keokuk Limestone. This information will be used to define potential flow paths for dissolved contaminants; however, for complete characterization of contaminant movement, additional information is required. This information includes parameters that define the contaminant's fate (persistence) and mobility. As discussed in Section 3.2.2.3, the persistence and mobility of the specified contaminants are fairly well known and include site-specific information collected by the USGS. Where site-specific information is not available, best engineering judgment values have been assigned. Because of the inherent uncertainties associated with contaminant transport modeling, gathering additional site-specific persistence or transport parameters may not be warranted.

3.5.2 Radioactive and Chemical Contaminants

The data requirements regarding contaminant concentrations are as follows:

• Springs in drainages that could be potentially impacted by runoff from the training area and the chemical plant area will be analyzed for potential site contaminants identified for the joint sampling effort.

• Sampling and analysis are needed to obtain background groundwater concentrations of uranium and to further evaluate background groundwater concentrations of other inorganic constituents.

• To confirm the extent of contamination, additional wells will be installed in the southeastern area of the chemical plant and will be sampled for uranium and other potential site contaminants that have been identified for the chemical plant area.

- Additional groundwater samples will be collected from selected wells and analyzed for certain metals to confirm the concentrations of potential site contaminants and other selected constituents. The specific metals and wells to be sampled are identified in Chapter 4.

- Groundwater from temporary sampling points (e.g., well point samples) near the bottom of the Southeast Drainage will be collected and analyzed for uranium and nitroaromatic compounds.

3.5.3 Ecological Resources

The EPA (1989b) has developed guidance regarding information needed to establish a relationship between environmental contaminants and observed ecological effects. This information includes (1) characterization of the nature, extent, and magnitude of contamination; (2) ecological surveys to identify biota potentially at risk of exposure and to establish whether adverse ecological effects have occurred; and (3) toxicity tests to identify potential ecological impacts and to establish a link between the toxicity of the hazardous wastes and contaminants and any realized adverse ecological effects. These data are necessary to determine whether the elevated levels of potential ecological site contaminants reported from Burgermeister Spring and the Southeast Drainage pose an unacceptable risk to ecological resources of the area. Data needs for performing an ecological risk assessment for Burgermeister Spring and the Southeast Drainage include information on (1) the nature and extent of contamination, (2) biota associated with and potentially exposed to contaminants, and (3) the current level of toxicity present in the sediment and surface water.

Activities to address specific ecological data requirements include the following:

- Media toxicity tests using a suite of biota (invertebrates and vertebrates) will be conducted for surface water and sediment at Burgermeister Spring and for surface water at the Southeast Drainage to determine if current levels of contamination pose a threat to biota.

- Surveys of aquatic macroinvertebrates and fish will be conducted at Burgermeister Spring, the Southeast Drainage, and suitable reference sites to identify biota most at risk of exposure and to identify realized adverse ecological effects.

- If toxicity tests suggest lethal or sublethal effects, qualitative surveys for amphibians and reptiles will be conducted along Burgermeister Spring, the Southeast Drainage, and suitable reference sites to identify vertebrate biota potentially at greatest risk of exposure to contaminants.

- Sediment and surface water samples will be collected at Burgermeister Spring and analyzed for nitroaromatics, uranium, arsenic, chromium, lead, mercury, selenium, silver, and nitrate by using appropriate analytical methods (e.g., with suitable detection limits).

- Surface water samples will be collected at the Southeast Drainage and analyzed for chromium, copper, lead, manganese, silver, zinc, uranium, nitrate, and nitroaromatics by using appropriate analytical methods (e.g., with suitable detection limits).

- Tissue analyses for potential site contaminants may be necessary to evaluate bioconcentration in selected terrestrial receptors and aquatic biota if toxicity tests suggest lethal or sublethal effects from exposure to contaminants. This information would also be useful for estimating contaminant transfer to federal- and state-listed fish and wildlife species.

3.6 PRELIMINARY IDENTIFICATION OF REGULATORY REQUIREMENTS

A preliminary list of key environmental regulations and guidelines that may be pertinent to the two GWOUs is presented in Table 3.4. As the RI/FS process progresses, this list will be used to develop the "applicable or relevant and appropriate requirements" (ARARs) and "to-be-considered" requirements (TBCs) that could be relevant to cleanup activities taken within the scope of these operable units. An initial list of potential regulations is identified at this stage of the RI/FS process to (1) support the development of alternatives for the final groundwater response, (2) initiate communication with and receive input from the state of Missouri and EPA Region VII on regulatory requirements important to activities conducted at the areas defined by the GWOUs, and (3) support the planning of field activities.

Individual requirements that have been established pursuant to the regulations and guidelines listed in Table 3.4 can be divided into three categories: location-specific, contaminant-specific, and action-specific requirements. This categorization can be applied to plan coordinated response actions and to track compliance for the GWOUs according to the specific contaminants that are present (such as nitrates and uranium), the discrete locations that are affected (such as Burgermeister Spring), and the cleanup activities that could be taken (such as excavation). The preliminary list of regulations will be refined and the pertinence of specific requirements will be assessed as detailed information becomes available for the final response action.

The general process for developing and evaluating ARARs and TBCs is described in Appendix G of the FS for the chemical plant area (DOE 1992b); many of the requirements associated with the regulations listed in Table 3.4 are detailed in that discussion. Additional requirements that may be germane to the final response actions for the GWOUs include contaminant-specific limits for water given in the Safe Drinking Water Act, the Clean Water

TABLE 3.4 Key Environmental Requirements and Guidelines Potentially Considered for the Final Response Actions for the Groundwater Operable Units

Federal Laws

Antiquity Act; Historic Sites Act
Archeological and Historic Preservation Act of 1974
Archeological Resources Protection Act of 1974
Atomic Energy Act of 1954, as amended
Clean Air Act of 1963, as amended
Clean Water Act, as amended (also referred to as Federal Water Pollution Control Act of 1972, as amended)
Endangered Species Act of 1973, as amended
Fish and Wildlife Coordination Act of 1934, as amended
Floodplain Management (Executive Order 11988)
National Historic Preservation Act of 1966, as amended
Noise Control Act, as amended
Protection and Enhancement of the Cultural Environment (Executive Order 11593)
Protection of Wetlands (Executive Order 11990)
Safe Drinking Water Act of 1974
Soil and Water Resources Conservation Act of 1977
Solid Waste Disposal Act, as amended by the Resource Conservation and Recovery Act of 1976, as amended by the Hazardous and Solid Waste Amendments of 1984
Uranium Mill Tailings Radiation Control Act of 1978

State Laws

Missouri Air Conservation Law
Missouri Air Pollution Control Regulations
Missouri Air Quality Standards
Missouri "Any-Use Soil Levels"
Missouri Clean Water Law
Missouri Drinking Water Act
Missouri Drinking Water Regulations
Missouri Hazardous Substance Rules
Missouri Hazardous Waste Management Law and Regulations
Missouri Land Reclamation Act
Missouri Radiation Regulations
Missouri Solid Waste Law
Missouri Solid Waste Rules
Missouri Water Pollution Control Regulations
Missouri 401 Water Quality Certification
Missouri Water Quality Standards
Missouri Wildlife Code

DOE Orders

Order 5400.3, Hazardous and Radioactive Mixed Waste Program
Order 5400.5, Radiation Protection of the Public and the Environment
Order 5820.2A, Radioactive Waste Management

Act, and parallel state laws. A detailed discussion of environmental requirements that are important to this final response action will be presented in the FSs to be prepared for the GWOUs.

4 WORK PLAN RATIONALE

The preliminary evaluation of the GWOUs presented in Section 3 indicates that additional data must be collected to support decisions that would be made regarding the operable units. Additional data will be collected as part of characterization activities performed in the RIs to fulfill the data requirements summarized in Section 3.5.

As discussed in Chapter 1, a joint sampling effort was planned and has been conducted at the chemical plant area and the ordnance works area to confirm the evaluation presented in this work plan. The joint sampling included (1) collection of groundwater samples for two quarters and analysis of unfiltered samples for all potential site contaminants and other selected constituents identified at both the chemical plant area and the ordnance works area (all analyses of metals were conducted on both filtered and unfiltered samples), (2) collection of surface water samples at Burgermeister Spring locations that are routinely monitored by CE and DOE, and (3) collection of surface water samples at selected springs (see Section 4.1.7).

Water-level elevations were measured at the monitoring wells located at the ordnance works area and the chemical plant area in conjunction with the joint sampling activity. To minimize the effects of temporal variations, the water-level measurements were obtained at approximately the same time from all of the wells, prior to groundwater sampling.

To ensure that information of the requisite type, quantity, and quality is obtained to fulfill the objectives for these operable units, a strategy for data acquisition was developed. This strategy involves a seven-step process and follows a format recommended by the EPA (1993a-b). The results of this planning process are commonly termed by the EPA as data quality objectives (DQOs). The DQO process undertaken for the GWOUs is summarized in Section 4.1.

4.1 DATA QUALITY OBJECTIVES

4.1.1 Problem Statement

The preliminary evaluation presented in previous sections of this work plan indicates that the levels of potential site contaminants identified for the GWOUs may pose an unacceptable risk to human health and the environment. Although a substantial amount of data were available to support this evaluation, a limited amount of data are still needed to confirm the evaluation and to bound conclusions in the risk assessment regarding potential impacts to human health and the environment. Additional information is also needed to support the remedial action selection process to be presented in the FS.

4.1.2 Identifying the Decision

The primary decision to be made is whether or not potential site contaminant levels in the groundwater, surface water, and sediment at the GWOUs pose an unacceptable risk to human health and the environment and, therefore, require remediation. The nature and degree of impact, however, have to be evaluated in the context of current and projected plausible future land uses. On the basis of current knowledge regarding the GWOUs, site conceptual exposure models were developed to guide the preliminary identification of potential pathways of exposure for both human receptors and biota (Section 3.1). Current land use at the areas comprising the GWOUs is limited to a recreational visitor along Burgermeister Spring (Section 3.1). Future land use is projected to remain consistent with current land use. Calculations for an additional scenario, that of an on-site future resident (considered to be an implausible scenario for both site areas), will also be included in the risk assessments performed for the chemical plant area and the ordnance works area. The results of risk calculations for the on-site future resident are expected to provide the EPA with information for a worst-case scenario.

To determine whether or not the levels of potential ecological site contaminants at Burgermeister Spring and the Southeast Drainage pose an unacceptable risk to ecological resources of the area, a phased ecological risk assessment will be performed as part of the baseline risk assessment (Section 5.6). The available information on the biota inhabiting this surface water is limited and largely qualitative, and no information is available regarding the current level of toxicity exhibited by the surface water and sediments in this drainage. Thus, additional ecological and contaminant characterization and toxicity data for contaminated media are needed to assess the potential for adverse ecological effects resulting from contaminants in these springs in order to determine the ecological significance of any identified adverse risks.

If the levels of potential site contaminants pose an unacceptable risk to human health or the environment, remediation would be required. To support the selection of remedial alternatives, the hydrogeological model needs to be verified in a few specific areas. Potential remedial alternatives are discussed in Section 3.4.

4.1.3 Identifying the Input

The identification of data requirements summarized in Section 3.5 was based on the need for additional information to confirm the site conceptual exposure models presented in Section 3.1. Hydrogeological parameters must be obtained to improve the understanding, in a few specific areas, of the shallow groundwater system to support the selection of remedial alternatives for these operable units. Additional data on groundwater contaminants are needed to confirm the potential site contaminants and to verify the extent of contamination. Also needed for the chemical plant area is refinement of background values of radiological and inorganic (metals and anions) parameters in the shallow groundwater system. At Burgermeister Spring and the Southeast Drainage, further confirmation of surface water or sediment contamination and additional data on biota and media toxicity are needed before a definitive statement can be made regarding any potential environmental impacts (and their significance) from contamination.

Sampling and data evaluation conducted during the RI phase are expected to support remedial action decisions with regard to baseline risk in terms of providing the following data:

- Representative background concentrations of naturally occurring uranium and inorganic parameters in groundwater;
- Statistics (e.g., representative means) representing concentrations of potential site contaminants in the shallow groundwater system;
- Statistics (e.g., representative means) representing concentrations of potential site contaminants in surface water at selected springs, including Burgermeister Spring;
- Presence or absence data for state-listed species and other ecological receptors; and
- Determinations of ecological toxicity for surface water and sediment at Burgermeister Spring and the Southeast Drainage.

4.1.4 Defining the Domain of the Decision

On the basis of current and future land-use projections (Sections 3.1 and 4.1.2), the following areas (and specific media) within and around the GWOUs have been identified for further contaminant investigation or sampling to evaluate potential risk to human health:

- The groundwater beneath the chemical plant area;
- The groundwater beneath and springs in the ordnance works area; and
- Surface water and sediment in Burgermeister Spring and the Southeast Drainage.

A detailed discussion of potential pathways of exposure for the various potential receptors identified for the GWOUs is presented in Section 3.1 of this work plan.

4.1.5 Decision Rule

The primary use of data at both GWOUs will be to conduct the baseline risk assessment and to support the selection of remedial alternatives if required. The determination of whether remedial action is required will be based, in part, on the results of these assessments. The EPA strives to manage possible incremental cancer risks at NPL sites within a target range of 10^{-6} to 10^{-4} and to maintain a hazard index (for noncarcinogenic effects) of less than 1; however, additional factors, including risks associated with background concentrations of uranium and limitations in analytical methods, are also taken into consideration in making a risk management decision to determine whether remedial action is necessary or warranted. Other factors taken into consideration include ARARs, cost, available technologies, and the results of the ecological assessment. Should the decision be made that remedial action is required for groundwater or surface water at the GWOUs, the data would be used further to support the development and evaluation of alternatives for remedial action.

4.1.6 Developing Uncertainty Constraints

Sampling at the GWOUs will be conservatively designed so that, at the decision risk level, the probability of occurrence of false negatives is very low and the probability of false positives is moderately low. More specific qualitative and quantitative statements of uncertainty will be defined on the basis of consequences of an incorrect decision and will be presented in subsequent project reports.

4.1.7 Optimizing the Sampling Design

Specific sampling activities to be implemented in support of this work plan are described in the Appendix. Sampling activities needed to fulfill the hydrogeological data requirements (see Section 3.5) are as follows:

1. The installation and aquifer testing (i.e., packer and tracer tests) of two angle boreholes in the northern part and one in the western part of the chemical plant area. These areas have previously yielded high hydraulic conductivity values, indicating a preferred flow path. The angled holes will not be completed as monitoring wells.

2. Six wells will be installed and one well retrofitted to further refine information on flow direction and transport at the ordnance works area. The proposed locations of the new wells are shown in Figure 2.2 of the Appendix. Aquifer properties determined by conducting packer tests and by water-level elevations will be measured in these new wells, which will become monitoring wells. The following are the proposed designations, locations, and completion intervals of the new wells:

    - MWS 26, open to the weathered unit of the Burlington-Keokuk zone and clustered with MWS 5;

    - A cluster of wells MWD 25 and MWS 25, open to the unweathered and weathered zones of the Burlington-Keokuk, respectively, west of MW-4005 and east of MW 8;

- MWD 23, open to the unweathered zone of the Burlington-Keokuk and clustered with MWS 23;
- MWD 107, open to the unweathered zone of the Burlington-Keokuk and clustered with MWS 107;
- MWS 112, open to the weathered zone of the Burlington-Keokuk and clustered with USGS 7; and
- USGS 7, which will be retrofitted and will be open to the unweathered zone, resulting in a new well identification of MWD 112, and clustered with MWS 112.

3. Data on hydraulic conductivity (i.e., slug tests) will be collected on all of the untested existing wells at the chemical plant area and the training area to augment the data set and confirm the hydrogeological conceptual model.

To fulfill contaminant data requirements, the following sampling activities will be performed:

1. Two additional wells, open to the weathered part of the Burlington-Keokuk Limestone, will be installed at the chemical plant area to bound the extent of contamination to the southeast (see Figure 3.4 of the Appendix). The two proposed wells (i.e., MW-4024 and MW-4025) will be installed southeast of MW-4020; well MW-4020 is currently located farthest to the southeast and is a well in which total uranium has been detected consistently. These wells will be sampled and analyzed for the potential site contaminants that have been identified for the chemical plant area.

2. Monitoring wells currently located on the training area will be sampled and analyzed for total uranium and specific metals to provide background concentrations.

3. After the joint DOE-CE sampling effort provides two additional quarters of data for all of the potential site contaminants and selected other constituents, sufficient data on the magnitude and extent of contaminants will generally be available to conduct the baseline risk assessments for human health at the chemical plant and the ordnance works areas. For some wells (e.g., retrofitted wells MW-3024 and MW-3025 at the chemical plant area that have been substituted for MW-3008), few samples are available to date; however, the number of samples needed for each well to conduct the baseline risk assessment is not absolute; the amount of data needed must be based partially on a

consideration of contaminant-level trends to date and professional judgment.

Pending the results of the joint sampling effort, the wells listed in Table 4.1 may require one or more additional rounds of sampling and analysis for the specified constituents; sampling will be included in the

TABLE 4.1 Data Requirements at Specific Wells for Select Potential Site Contaminants and Other Constituents[a]

Well	Parameter[b]
Chemical Plant Area	
MW-2012[c]	Manganese
MW-2030	Iron, manganese
MW-2032	Iron, manganese
MW-2033	Iron, manganese
MW-2037	Lithium, manganese
MW-2038	Lithium, manganese
MW-2039	Antimony
MW-2040	Molybdenum
MW-2041	Manganese
MW-3025	Manganese
MW-3027	Antimony
MW-4001	Antimony
MW-4006	Antimony
MW-4012	Molybdenum
MW-4016	Molybdenum, iron
Ordnance Works Area	
MWS 18	Sulfate

[a] Further data may be collected, pending the results of the joint sampling data.

[b] These constituents have been elevated in at least one sampling round in the listed well. Following the joint sampling effort, the listed monitoring wells will have less than six samples available for the specified constituent, so additional data may be needed. For iron and manganese, the additional samples may be required to determine the concentration relationship between filtered and unfiltered samples.

[c] Well MW-2012 is being used as a replacement for abandoned well MW-4017, which had one elevated manganese concentration (97 µg/L) in an unfiltered sample.

sampling plan. Also, if the joint sampling effort detects elevated levels of nitrate for monitoring wells in the ordnance works area, additional rounds of sampling for nitrate may be needed.

4. The following 15 springs will be sampled and analyzed for potential site contaminants as part of the joint sampling effort: SP-5101, SP-5201, SP-5303, SP-5402, SP-5501, SP-5504, SP-5601, SP-5602, SP-5605, SP-5612, SP-6301 (Burgermeister Spring), SP-6303, SP-6306, SP-6501, and SP-6601.

5. Groundwater data will be collected for uranium and nitroaromatic compounds at six temporary sampling points (e.g., well point samples) near the bottom of the Southeast Drainage. If possible, the samples will be symmetrically centered on the drainage, with equal numbers of samples taken from the east and west sides of the drainage.

To fulfill ecological data requirements, the following sampling activities will be performed:

- Samples of surface water will be collected from Burgermeister Spring and the Southeast Drainage and will be analyzed for the ecological contaminants of concern by using methods with appropriate detection limits.

- Qualitative and quantitative surveys of biota will be performed at Burgermeister Spring, the Southeast Drainage, and appropriate reference locations to adequately characterize the ecological resources and to determine the status of state-listed species in the spring.

- Samples of surface water and sediment from Burgermeister Spring and of surface water from the Southeast Drainage will be collected and will be used in screening toxicity tests to determine whether current levels of contaminants in these media are toxic to biota. If toxicity is detected, additional toxicity tests will be conducted by using serial dilutions of contaminated surface water and sediment.

4.2 DATA QUALITY AND QUANTITY REQUIREMENTS

An integral part of the strategy for data collection is the identification of the desired quality and quantity of analytical data so that the data generated are adequate to support risk assessment to a predetermined level of accuracy. The requirements for the quality of data collected for project activities related to the two GWOUs to date are presented and discussed in the *Environmental Data Administration Plan* (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992b) and the *Final Chemical Data Acquisition Plan* (IT Corporation 1994d). These plans contain the minimum goals for precision, accuracy, representativeness, completeness, and comparability (PARCC) of any data set collected for the GWOUs; however, to support the joint DOE-CE sampling effort discussed in Chapters 1 and 3 of this work plan, a common set of data quality and quantity requirements will be determined and implemented (see the Appendix for a detailed discussion).

4.3 SUMMARY OF OTHER SUPPORTING DOCUMENTS

Currently, both DOE and CE have their respective community relations plan, health and safety plan, and QAPjP to support RI/FS activities if separate RI/FS processes are undertaken. The status and content of these plans are briefly summarized in Sections 4.3.1 through 4.3.3. If a joint RI/FS process were undertaken, these plans would be used to establish a common set of requirements with regard to community relations, health and safety, and quality assurance/quality control.

4.3.1 Community Relations Plans

The existing community relations plans for the site areas (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a; IT Corporation 1992e) describe the policy and procedures for site personnel interacting with the general public. The community relations programs, as discussed in these plans, ensure meaningful exchanges of information on such matters as potential health impacts, environmental issues, response-action construction plans, project costs, and specific site activities.

4.3.2 Health and Safety Plans

Field activities will be performed in accordance with requirements in the project health and safety plans (DOE 1994b; IT Corporation 1994e). The plans include the safety standards that must be met by all personnel during the conduct of their assignments. Addressing the health and safety of on-site personnel will also minimize any potential impacts to the general public and the nearby environment. Key elements of these plans are the use of appropriate protective equipment and safeguards and the performance of specific tasks under the supervision of trained technicians and safety specialists. On-site personnel are trained to be cognizant of appropriate safety equipment and procedures, locations and types of on-site hazards, standard operating procedures (SOPs), and procedures to be followed in emergency situations. Health and safety training and medical surveillance of all potentially exposed personnel are required elements of these plans.

4.3.3 Quality Assurance Project Plans

The quality assurance and quality control requirements implemented in activities such as sample collection are provided by the *Environmental Quality Assurance Project Plan* (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992c) and the *Final Chemical Data Acquisition Plan* (IT Corporation 1994d). These plans meet the applicable requirements of EPA's QAMS 005/80, *Interim Guidelines and Specifications for the Preparation of Quality Assurance Project Plans*, by addressing the 16 quality assurance elements specified for environmentally related measurements (EPA 1983).

The data generated for the GWOUs are anticipated to be of such quality as to accurately define the nature and extent of radioactive and chemical contamination. The attainment of the desired quality of data is achieved through the implementation of SOPs for activities, including the following: document control; field activities; chain of custody; equipment calibration; laboratory analyses; data validation, verification, reduction, and reporting; internal quality-control checks; audits and surveillances; preventive maintenance; corrective actions; and document hierarchy.

The SOPs for field sampling are developed to standardize, where possible, sampling procedures to ensure that samples are comparable to, and compatible with, data collection activities at the chemical plant area and the ordnance works area. Available field SOPs include those for sample collection, sample identification, sample preservation, sample packaging and handling, sampling quality control, quality assurance, and equipment calibration and maintenance.

Procedures related to the management of environmental data collected by DOE and CE are discussed in the *Environmental Data Administration Plan* (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992b) and the *Final Data Management Plan* (IT Corporation 1990), respectively. Laboratory QAPjPs and SOPs are used to specify quality control requirements to demonstrate attainment of the specified PARCC goals. The data generated are subjected to an established procedure of data evaluation, reduction, and reporting.

5 REMEDIAL INVESTIGATION/FEASIBILITY STUDY TASKS

The EPA has provided a framework consisting of 14 tasks to be performed during the RI/FS process. This framework will be used in carrying out a comprehensive program that addresses site investigation, risk assessment, and evaluation of technologies and alternatives for the RI/FS being undertaken for the GWOUs. Existing documents — including the *Project Management Contractor Quality Assurance Program* (DOE 1992e), the *Environmental Quality Assurance Project Plan* (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992c), and the *Environmental Data Administration Plan* (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992b) for the chemical plant area; and the *Final Chemical Data Acquisition Plan* (IT Corporation 1994d) and the *Final Data Management Plan* (IT Corporation 1990) for the ordnance works area — will be used to direct and manage RI/FS activities and to implement quality assurance and quality control requirements for the respective GWOUs. These documents address applicable DOE, CE, and EPA requirements. The RI/FS tasks and the phased approach suggested by the EPA are presented in Figure 5.1. Site-specific activities carried out to fulfill each of the 14 tasks are discussed in Sections 5.1 through 5.14. For ease of presentation, the discussions presented in this chapter assume that DOE and CE will conduct separate RI/FS processes for the GWOUs; however, whether the process should be undertaken jointly or separately has not yet been determined (see Chapter 1).

5.1 TASK 1: PROJECT PLANNING

The contents of this work plan and the associated supporting documents (i.e., sampling and analysis plan, health and safety plan, and community relations plan) describe planning activities for the project. Activities under this task include the following:

- Collecting and evaluating available historical and characterization data or information (Section 2);
- Developing a site conceptual exposure model on the basis of available information (Section 3.1);
- Identifying data needs (Section 3.5) and developing DQOs (Section 4.1);
- Identifying preliminary remedial action objectives and potential remedial alternatives (Sections 3.3 and 3.4);
- Identifying potential treatability studies, as appropriate; and
- Identifying preliminary ARARs (Section 3.6).

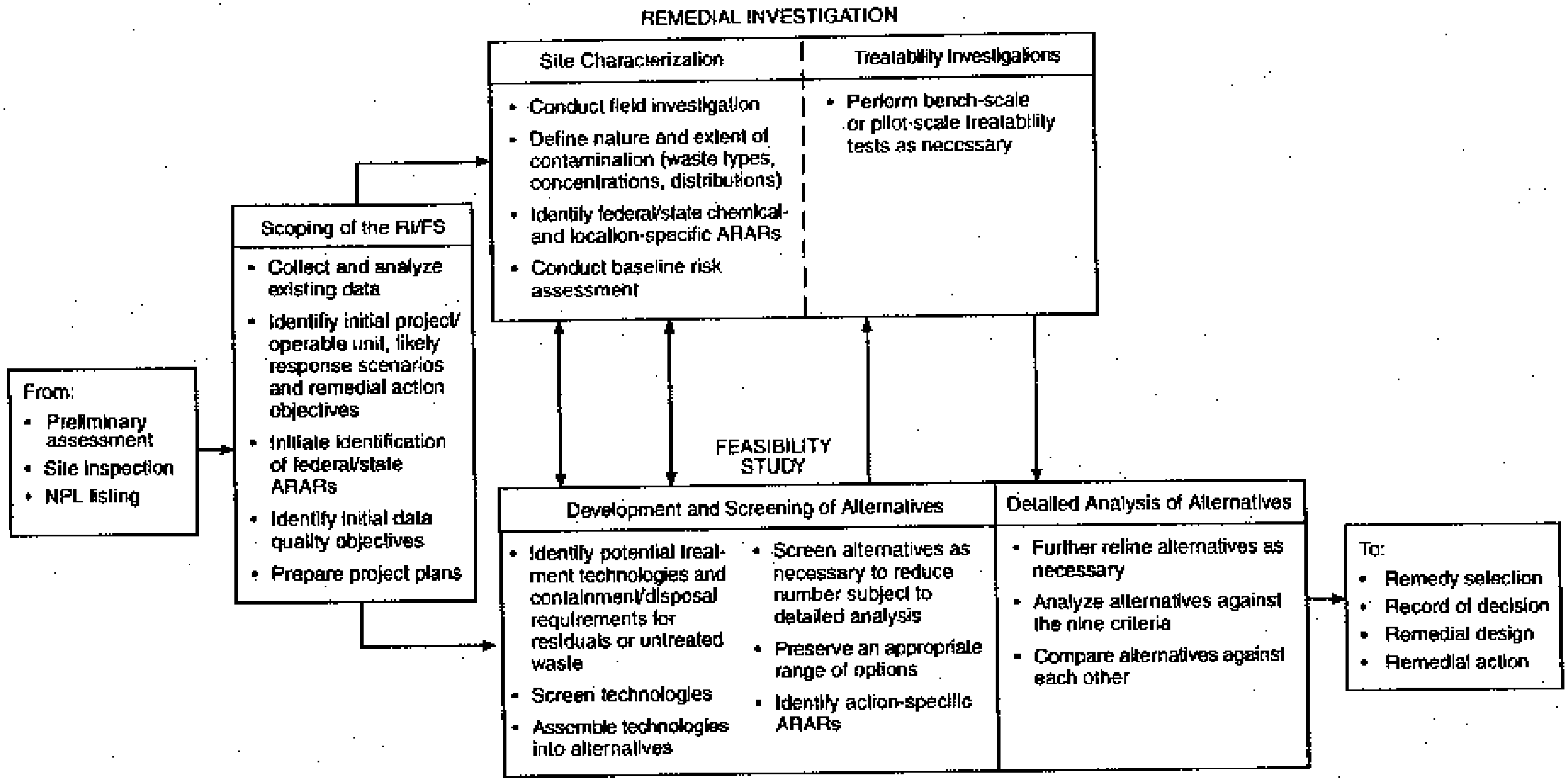


FIGURE 5.1 Summary Diagram of the Remedial Investigation/Feasibility Study Process (Source: EPA 1988)

5.2 TASK 2: COMMUNITY RELATIONS

Task 2 incorporates all efforts related to the preparation and implementation of the community relations plans (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a; IT Corporation 1992e). The DOE community relations plan includes a description of the chemical plant area, community relation strategies, lists of contacts and interested parties, and a description of activities that DOE is undertaking to ensure full public participation. So far, information related to site remedial activities has been provided to the public through news releases, fact sheets, public meetings, and briefings. The DOE will continue to use these mechanisms to inform the public regarding activities for the GWOU at the chemical plant area. In addition, the public has access to various documentation related to the DOE RI/FS process for this GWOU at several repository locations (e.g., St. Charles City/County Library, St. Charles, Missouri) and a public reading room located at the chemical plant area.

The CE community relations plan includes background information about the ordnance works area and a description of activities that CE is undertaking to ensure full public participation. The CE maintains a current distribution list comprising more than 250 addresses for newsletters and other information packages that are also available to any local citizen by request. The CE solicits input from the concerned public through a technical review committee that is composed of representatives from the Francis Howell School District, the Weldon Spring Heights subdivision, the Missouri Department of Natural Resources, the Missouri Department of Conservation, the U.S. Department of the Interior, DOE, and citizens' environmental groups. Finally, CE has established public information repositories at the St. Charles County Public Library (Kisker Road Branch) and at the site office of the ordnance works area.

5.3 TASK 3: FIELD INVESTIGATION

Task 3 involves activities to be undertaken during the RI phase. Upon concurrence of the sampling and analysis plan by the EPA and state agencies, subcontractors will be procured. This task is complete when the subcontractors are demobilized from the field. The following activities will be conducted as part of this task:

- Mobilization of field activities,
- Media or contaminant sampling,
- Hydrogeological investigations,
- Ecological investigations, and
- Field measurements.

Plans for field investigations are documented in the field sampling plan and are undertaken in accordance with the DQOs established for the GWOUs. Basically — to the extent practicable — the data needs for these operable units (Section 3.5) have been categorized into those that will provide a contaminant profile of the various environmental media of concern, provide further characterization of the hydrogeological features, and characterize the ecological biota.

5.4 TASK 4: SAMPLE ANALYSIS AND VERIFICATION

For Task 4, samples collected during the field investigation will be analyzed in accordance with the data quality requirements (DQRs) established for these operable units. The DQRs are described in more detail in the Appendix.

The verification program is designed primarily to ensure that documentation and data are reported in compliance with established DQRs and SOPs. The sample verification process includes a review of sample identification and preservation, chain-of-custody documentation, analytical holding times, and completeness of data reported.

Validation of the data collected is also performed to ensure that the quality of data is adequate for its intended use and is in compliance with the established DQRs. Procedures covering this task are described in the *Environmental Data Administration Plan* (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992b) and the *Final Data Management Plan* (IT Corporation 1990).

5.5 TASK 5: DATA EVALUATION

Task 5 involves analysis of the data after verification-and-validation activities have been performed. The task begins when the first set of validated data is received and ends during preparation of the RI reports or supplemental investigations when the determination is made that no additional data are required. The following activities are typically performed under Task 5:

- Comparing potential site-related contaminant concentrations with values representative of background levels, and

- Developing a data set for use in the baseline risk assessments.

5.6 TASK 6: RISK ASSESSMENT

Task 6 includes efforts related to the performance of baseline risk assessments for the two GWOUs. These assessments will analyze, for current and future land uses, the potential adverse human health and environmental effects caused by contaminants identified at the GWOUs. The results of the assessments will be used to support activities related to the screening of alternatives and the development of cleanup limits for contaminants. The activities that will be performed and presented in the baseline risk assessment reports include those related to (1) identification of the contaminants of concern for each of the

GWOUs, from the standpoint of both human health and ecological concerns; (2) exposure assessment, including modeling as appropriate; (3) toxicity assessment; and (4) risk characterization.

In addition to historical information, data gathered from characterization activities during the RIs will be evaluated according to procedures recommended by the EPA (1989c-d) to identify the contaminants of concern. This same subset of data will also be used to derive the exposure point concentrations for the identified contaminants of concern. Factors needed to perform the exposure assessment will be site-specific, to the extent possible, or derived from EPA-recommended sources. Toxicity values are available from the EPA through the *Integrated Risk Information System* database; RfDs and slope factors for the appropriate chemical contaminants of concern will be obtained from this database. Radiological risks will be estimated on the basis of dose conversion factors (i.e., millirems per picocurie) and unit risk factors (i.e., risk per millirem), as discussed in Section 4.1 of the BA for the chemical plant area (DOE 1992a). In addition, the EPA has recently developed cancer factors per unit of intake for radioactive contaminants that are analogous to slope factors for chemical carcinogens, and these factors will also be used to estimate risks from exposure to radioactive contaminants. The results from these methodologies will be compared in the baseline risk assessments. Chemical and radiological risks will be analyzed separately to allow for a clear presentation of the source of risk (i.e., radiological or chemical).

5.7 TASK 7: TREATABILITY STUDIES

Task 7 (treatability studies) is performed to provide information needed for alternatives to be fully developed and evaluated during the RI/FS process. Treatability studies can provide data important to an adequate evaluation of certain technologies for a given response action. Such data include information on performance, operating parameters, and cost in sufficient detail to support the process of remedy selection and the subsequent design activities. This task can involve efforts for bench-scale or pilot-scale testing, including associated procurement activities. Treatability studies can be identified at different times during the RI/FS process (e.g., from the scoping stage through the screening of preliminary alternatives). For the GWOUs, a search of the literature will be performed prior to any decisions regarding the undertaking of a treatability study. The purpose of the literature search will be to identify potential methods for extraction and treatment; however, because of the properties of the shallow groundwater system (i.e., low transmissivity, low specific yield, and imprecisely known fracture/conduit geometry), the probability of finding an effective remediation strategy is low.

5.8 TASK 8: REMEDIAL INVESTIGATION REPORT

Task 8 involves the activities undertaken to prepare and complete the RI reports. After evaluation of data generated through the joint sampling effort, a decision will be made as to whether a combined RI report or separate RI reports will be prepared by DOE and CE.

The format of these reports will be similar to previous RI reports prepared by DOE and CE (DOE 1989, 1992d). These reports are expected to include the following:

- Complete descriptions of the GWOUs.

- Brief chronologies of remedial activities undertaken or planned to lend rationale for the characterization activities completed.

- Brief summaries of data relevant to the GWOUs but collected prior to the RI activities for these operable units.

- Summaries of data generated through the joint sampling effort and other sampling activities to fulfill data requirements discussed in Section 3.5. A brief summary discussing validation and verification of data will be included. Data interpretation (e.g., contaminant distribution and comparison of background concentrations to potential site contaminant concentrations) will be discussed and illustrated by using tables, figures, and maps.

- Summaries of the baseline risk assessments performed for the GWOUs. Separate reports will be prepared to present the analysis and results of the baseline risk assessments performed for these operable units.

5.9 TASK 9: REMEDIAL ALTERNATIVES DEVELOPMENT AND SCREENING

Task 9 involves screening the initial development and evaluation of remedial action alternatives for the GWOUs that will be fully evaluated under Task 10. The objective of the screening process undertaken within Task 9 is to narrow the number of alternatives that will undergo detailed evaluation. This process begins with identification of the remedial action objectives, then proceeds through narrowing of the list of potential technologies on the basis of applicability and effectiveness, and ends with identification of a set of remedial action alternatives. Each remedial action alternative may involve application of a single technology or a combination of two or more technologies. Task 9 consists of the following activities:

- Identifying response objectives and response actions;

- Listing potential remedial technologies;

- Screening remedial technologies and process options on the basis of site-specific criteria;

- Assembling potential remedial action alternatives from the screened technologies and process options;

- Evaluating potential remedial action alternatives on the basis of screening criteria (i.e., effectiveness, implementability, and cost); and
- Identifying candidate alternatives for remedial action to undergo detailed evaluation in Task 10.

5.10 TASK 10: DETAILED ANALYSIS OF ALTERNATIVES

The remedial alternatives that pass the screening process during Task 9 will be evaluated in detail within Task 10. The nine criteria for evaluating these alternatives are as follows:

1. Overall protection of human health and the environment;
2. Compliance with ARARs;
3. Long-term effectiveness and permanence;
4. Reduction of toxicity, mobility, and volume;
5. Short-term effectiveness;
6. Implementability;
7. Cost;
8. Acceptance by the state; and
9. Acceptance by the community.

A summary of each alternative, including the no-action alternative, is prepared on the basis of these criteria. The use of these nine criteria is consistent with the NCP.

5.11 TASK 11: FEASIBILITY STUDY REPORT

Task 11 involves the coordination and preparation of the FS reports. The task is complete when the FS reports are released to the public. The following are activities under this task:

- Formatting data for report purposes;
- Preparing associated graphics;
- Writing the reports;
- Printing and distributing the reports;

- Responding to review comments; and
- Revising the reports on the basis of agency and public comments.

The format of the FS reports for the GWOUs will be similar to previous FS reports prepared by DOE and CE (DOE 1990a, 1992b). Further, the DOE report will incorporate NEPA values, as recommended by DOE's NEPA policy (DOE 1994a).

5.12 TASK 12: POST-REMEDIAL INVESTIGATION/FEASIBILITY STUDY SUPPORT

Task 12 includes efforts to prepare the proposed plans and responsiveness summaries, support development of the RODs, and conduct any predesign activities. Task 12 activities include the following:

- Preparing the proposed plans,
- Attending public meetings,
- Preparing the responsiveness summaries and draft RODs,
- Finalizing documents in response to agency and public comments,
- Preparing the predesign reports, and
- Completing the conceptual designs.

The proposed plans are summary documents that identify the preferred alternative for remedial action and the rationale for selection, describe the alternatives evaluated in the RI/FS process, and solicit public review and comment on all screened alternatives presented in the FSs. The format of the proposed plans for the GWOUs will be similar to previous proposed plans prepared by DOE and CE (DOE 1990b, 1992c; U.S. Department of the Army 1993). Preparation of the responsiveness summaries and the RODs will be initiated following public review of the RI/FS documents and comment upon the proposed plan.

5.13 TASK 13: ENFORCEMENT SUPPORT

Task 13 includes efforts during the RI/FS process that are associated with enforcement aspects of the project, typically concerning potentially responsible parties. Because DOE and CE have assumed responsibility for the chemical plant area and the ordnance works area, respectively, Task 13 is not applicable to this project.

5.14 TASK 14: MISCELLANEOUS SUPPORT

Task 14 is used to report on work that is associated with the project but does not fall under any of the other established RI/FS tasks. No activities under this task have been identified for the GWOUs.

6 PROJECT SCHEDULE

A DOE-generated schedule for environmental compliance activities planned for the GWOU of the chemical plant area is shown in Figure 6.1. This schedule was developed in accordance with DOE's project financial plan for fiscal year 1995 and shows the events projected through the point at which the ROD is issued. This schedule shows the relationships between the tasks and their projected durations; however, specific dates beyond 1995 should not be considered as firmly established because funding is based on the out-year budget cycle. The CE expects to be able to comply with a similar schedule for the GWOU of the ordnance works area. The schedule consists of the following major components:

- Completion of scoping and planning for the GWOU. Scoping involves the early incorporation of public comment and concerns into the RI/FS process. This scoping may include, for example, consideration of specific remedies for site cleanup or evaluation of various health and environmental concerns. Documentation for the GWOU during the scoping phase includes this RI/FS work plan and the sampling plan.

- Completion of characterization activities.

- Completion of the RI/FS process and issuance for public comment of the RI reports, baseline risk assessment reports, FS reports, and proposed plans.

- Preparation of responsiveness summaries to address public comments received on the RI/FS reports, and preparation and issuance of the RODs. The RODs are projected to be issued in 1998. Remedial design and remedial action activities consistent with the NCP will be initiated following issuance of the RODs.

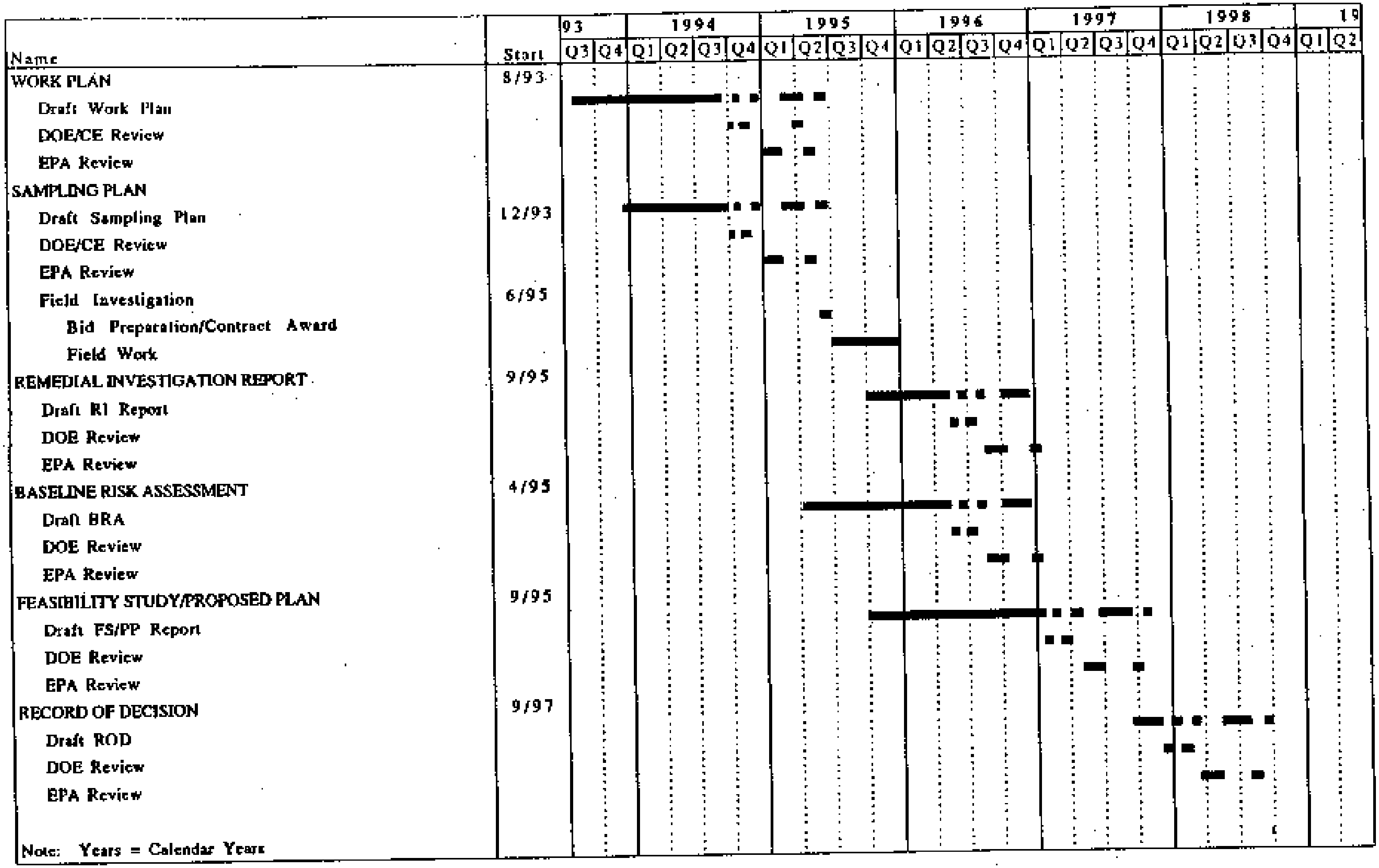


FIGURE 6.1 Schedule for the Remedial Investigation/Feasibility Study of the Groundwater Operable Units at the Chemical Plant Area and the Ordnance Works Area

7 PROJECT MANAGEMENT

7.1 PROJECT ORGANIZATION

Remedial actions associated with the GWOUs are being conducted by DOE and the Army at the chemical plant area and the ordnance works area, respectively. Remedial activities at the chemical plant area are administered by the Office of Environmental Restoration, Eastern Area Programs Division (Figure 7.1), through the WSSRAP. Responsibility for management and technical direction of remedial activities has been delegated to the DOE Oak Ridge Operations Office, which has established a project office at the chemical plant area. The Eastern Area Programs Division is also responsible for policy decisions related to conducting remedial actions at the chemical plant area and for coordination with CE, which shares the cost of this project. The CE, Missouri River Division, is the headquarters of the Kansas City District. The Missouri River Division is responsible for policy decisions related to conducting remedial actions at the ordnance works area and for coordination with Headquarters, CE, in Washington, D.C. (Figure 7.2).

Five separate organizations are under contract to DOE to support implementation of this project:

- MK-Ferguson Company is the Project Management Contractor, assisting DOE in the planning and management of response action activities; Jacobs Engineering Group, Inc., is under contract to MK-Ferguson Company to provide technical support for the project.

- Argonne National Laboratory, Environmental Assessment Division, is the CERCLA/NEPA process management contractor and is responsible for planning and preparing appropriate environmental compliance documentation to support specific cleanup decisions.

- Oak Ridge Institute for Science and Education provides technical support, specifically by performing independent verification of completed response actions.

- Professional Analysis Inc. of Oak Ridge, Tennessee, provides administrative support to the DOE project office.

- Lockwood Greene Technologies of Oak Ridge, Tennessee, provides engineering design and engineering management support to the DOE project office.

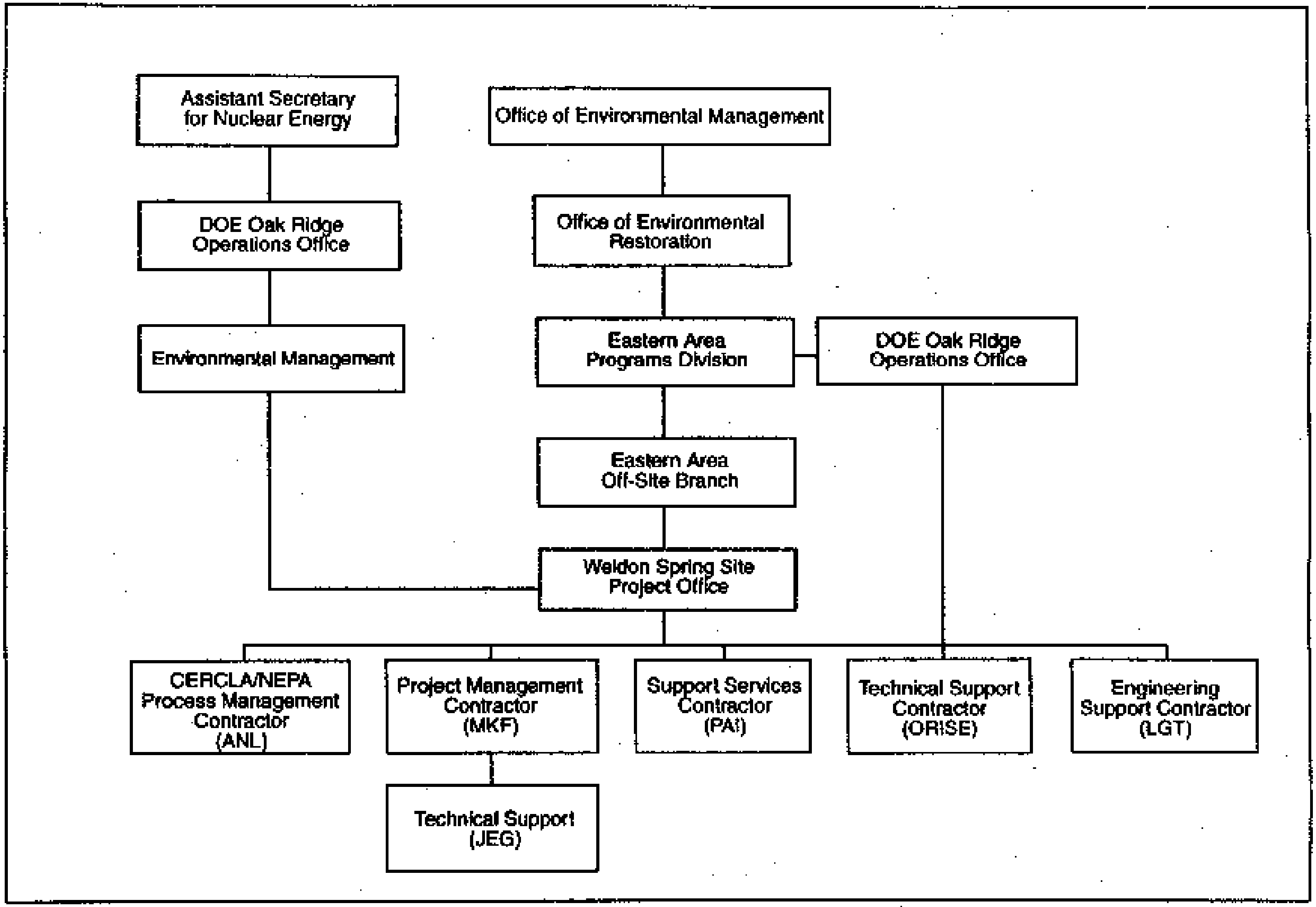


FIGURE 7.1 Project Management Structure for the U.S. Department of Energy (ANL = Argonne National Laboratory; JEG = Jacobs Engineering Group, Inc.; LGT = Lockwood Greene Technologies; MKF = MK-Ferguson Company; ORISE = Oak Ridge Institute for Science and Education; and PAI = Professional Analysis Inc.)

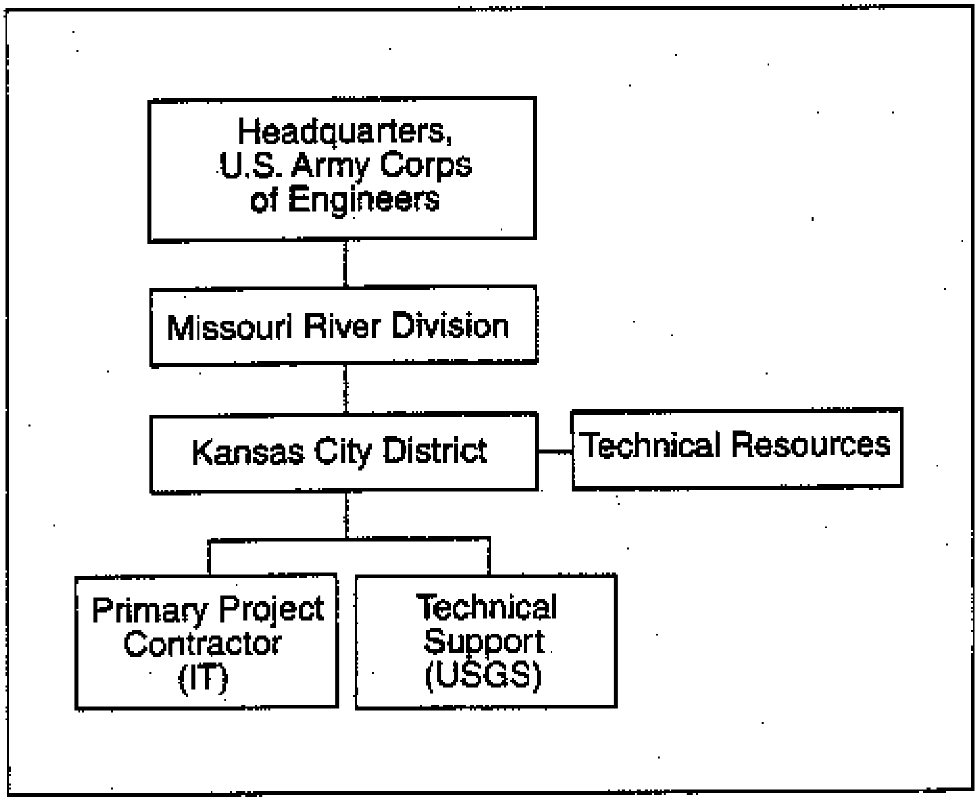


FIGURE 7.2 Project Management Structure for the U.S. Army Corps of Engineers

Two separate organizations are under contract to CE to support implementation of this project:

- International Technology Corporation assists in planning and providing technical support for the project.

- The USGS assists in gathering technical information to support the RI/FS and reviews data from both sites to ensure consistency.

7.2 PROJECT COORDINATION AND RESPONSIBILITIES

Remedial actions carried out by DOE and the Army at the chemical plant area and the ordnance works area are subject to EPA oversight under CERCLA. Oversight responsibilities for both areas are carried out by EPA Region VII. The Missouri Department of Natural Resources also has oversight responsibility for the ordnance works area, as defined by the FFA for the Army. The responsibilities of DOE, the EPA, the Army, and the Missouri Department of Natural Resources are defined in the respective FFAs (Sections 1.4.1 and 1.4.2).

The state of Missouri has designated the Missouri Department of Natural Resources to coordinate state involvement in this project. This department is responsible for ensuring that the appropriate state agencies are kept informed regarding project plans and activities.

The responsibilities of each of the major organizations under contract to DOE at the chemical plant area are as follows:

- MK-Ferguson Company (including Jacobs Engineering Group, Inc., as a subcontractor)

  - Provide overall project management support to DOE for the WSSRAP. This support includes implementation and documentation of activities related to health and safety requirements, cost control procedures, sample and data management, project schedule tracking, and training.

  - Administer procurement and quality assurance functions.

  - Perform general administrative functions.

  - Direct all engineering activities.

  - Provide technical input to the preparation of environmental documents.

  - Perform community relations duties.

- Argonne National Laboratory, Environmental Assessment Division

  - Plan and perform environmental analyses for CERCLA and NEPA compliance.

  - Provide an independent analysis of environmental studies, engineering feasibility, and cost-effectiveness of response action alternatives performed by other DOE contractors.

  - Prepare additional environmental compliance documentation, as needed.

- Oak Ridge Institute for Science and Education

  - Conduct radiological surveys to identify and designate properties in the vicinity that require response actions.

  - Conduct postresponse radiological surveys to provide independent verification of the cleanup effort, and prepare the requisite verification reports.

- Professional Analysis Inc.
  - Provide technical and administrative support to the DOE project office.
  - Review environmental documents, and advise the DOE project office on regulatory requirements.
  - Review and analyze resources as changes in funding and priorities occur.
  - Assist the DOE project office with the preparation or analysis (or both) of documents and reports for the annual budget process.
- Lockwood Greene Technologies
  - Provide technical review support of designs, reports, etc., to the DOE project office.
  - Provide staffing and management analysis support to the DOE project office.
  - Assist the DOE project office with the analysis of documents and reports for staffing, reprogramming, or contract modifications.

The responsibilities of each of the major organizations under contract to CE at the ordnance works area are as follows:

- International Technology Corporation
  - Ensure timely submission of all deliverables, and conduct final review.
  - Prepare any amendments to the current safety and health plan for the site, and address unforeseen issues relating to health and safety that may occur during field activities.
  - Organize the investigations, including overseeing field activities, serving as the site safety administrator, and assisting DOE and CE in compiling the report(s).
  - Prepare any amendments to the current *Chemical Data Acquisition Plan*, and assist DOE and CE in compiling the sampling plan.

- Serve as primary contact and technical consultant to project personnel regarding analytical issues.

- U.S. Geological Survey

    - Gather technical information to support the RI/FS.

    - Review data from both sites to ensure consistency.

    - Assist in performing any required treatability studies.

8 REFERENCES

Baes, C.F., and R.D. Sharp, 1983, "A Proposal for Estimation of Soil Leaching and Leaching Constants for Use in Assessment Models," *Journal of Environmental Quality* 12(1):17-28.

Bair, F.E., 1992, *The Weather Almanac*, 6th ed., Gale Research Inc., Detroit, Mich.

Bechtel National, Inc., 1987, *Hydrogeological Characterization Report for Weldon Spring Chemical Plant, Weldon Spring, Missouri*, DOE/OR/20722-137, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Oak Ridge, Tenn., July.

Bedan, D.E., 1991, letter from Bedan (Radioactive Waste Cleanup Coordinator, Division of Environmental Quality, Missouri Department of Natural Resources, Jefferson City, Mo.) to S. McCracken (Project Manager, U.S. Department of Energy, Weldon Spring Site Remedial Action Project, St. Charles, Mo.), April 12.

Boerner, A.J., 1986, *Radiological Survey of the August A. Busch and Weldon Spring Wildlife Areas, Weldon Spring Site, St. Charles County, Missouri*, Final Report, prepared by Oak Ridge Associated Universities, Oak Ridge, Tenn., for U.S. Department of Energy, April.

Boudou, A., and F. Ribeyre, 1989, "Fundamental Concepts in Aquatic Ecotoxicology," in *Aquatic Ecotoxicology: Fundamental Concepts and Methodologies, Vol. I*, A. Boudou and F. Ribeyre (editors), CRC Press, Inc., Boca Raton, Fla.

Bradley, P.M., et al., 1994a, "Microbial Degradation of Nitroaromatic Contaminants in Aquifers and Surface Soils," in *Proceedings of the 18th Annual Army Environmental Technology Symposium, 28-30 June 1994, Williamsburg, Virginia*, U.S. Army Environmental Center, Aberdeen Proving Grounds, Md.

Bradley, P.M., et al., 1994b, "Microbial Transformations of TNT and DNT in Contaminated Soils and Aquifer Materials at Weldon Spring, Missouri," in *Proceedings of the Second International Conference on Ground Water Ecology*, J.A. Stanford and H.M. Valett (editors), Atlanta, Ga., March 27-30, U.S. Environmental Protection Agency and American Water Resources Association, Herndon, Va.

Bradley, P.M., et al., 1994c, "Microbial Transformations of Nitroaromatics in Surface Soils and Aquifer Materials," *Applied and Environmental Microbiology* 60(6):2170-2175.

Carman, J., 1991, "Aquifer Characteristics of the Shallow Burlington-Keokuk Limestone at the Weldon Spring Site," in *Proceedings of the Geosciences Workshop*, DOE/OR/21548-197, published by MK-Ferguson Company and Jacobs Engineering Group, Inc., St. Charles, Mo., for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., Feb., pp. 155-201.

Chapman, C.H., 1975, *The Archaeology of Missouri I,* University of Missouri Press, Columbia, Mo.

Chapman, C.H., 1980, *The Archaeology of Missouri II,* University of Missouri Press, Columbia, Mo.

Clardy, S.A., 1995, letter from Clardy (Missouri Department of Health, Jefferson City, Mo.) to H. Hartmann (Argonne National Laboratory, Argonne, Ill.), with enclosures, April 26.

Crigler, D., 1992, personal communication from Crigler (Wildlife Management Biologist, August A. Busch Memorial Wildlife Area, St. Charles, Mo.) to G. Valett (Project Management Contractor, Weldon Spring Site Remedial Action Project, St. Charles, Mo.), as documented in memorandum from G. Valett to R. Ferguson (Jacobs Engineering Group, Inc., Weldon Spring Site Remedial Action Project, St. Charles, Mo.), May 21.

Daubel, K., 1992, personal communication from Daubel (U.S. Department of Army) to M. Sizemore (MK-Ferguson Company, Weldon Spring Site Remedial Action Project, St. Charles, Mo.), as documented in memorandum from M. Sizemore to M. MacDonell (Environmental Assessment and Information Sciences Division, Argonne National Laboratory, Argonne, Ill.), March 17.

Dickneite, D.F., 1988, letter from Dickneite (Environmental Administrator, Missouri Department of Conservation, Jefferson City, Mo.) to I. Hlohowskyj (Environmental Assessment and Information Sciences Division, Argonne National Laboratory, Argonne, Ill.), with enclosure, Aug. 24.

DOE: see U.S. Department of Energy.

Environmental Science and Engineering, Inc., 1993, *Weldon Spring Remedial Action Project 1992 Aquatic Biological Monitoring — WP 305, Final Report,* ESE No. 592-1043-0400, prepared by Environmental Science and Engineering, Inc., St. Louis, Mo., for MK-Ferguson Company, St. Charles, Mo., April.

EPA: see U.S. Environmental Protection Agency.

Figg, D.E., 1991, letter from Figg (Endangered Species Coordinator, Missouri Department of Conservation, Jefferson City, Mo.) to J.R. Powers (MK-Ferguson Company, St. Charles, Mo.), Nov. 26.

Fishel, V.C., and C.C. Williams, 1944, *The Contamination of Ground and Surface Waters by Liquid Waste from the Weldon Spring Ordnance Works,* U.S. Geological Survey, Lawrence, Kans.

Gaines, E.P., 1988, letter from Gaines (Data Manager, Missouri Department of Conservation, Jefferson City, Mo.) to I. Hlohowskyj (Environmental Assessment and Information Sciences Division, Argonne National Laboratory, Argonne, Ill.), with enclosure, Sept. 8.

Garstang, M., 1991, "Collapse Potential Evaluation of the Defined Study Area at the Weldon Spring Chemical Plant Site, Weldon Spring, Missouri," in *Proceedings of the Geosciences Workshop*, DOE/OR/21548-197, published by MK-Ferguson Company and Jacobs Engineering Group, Inc., St. Charles, Mo., for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., Feb., pp. 277-295.

Haas, D., 1978, *An Archaeological Survey of the Little Femme Osage/River Hills Area and the Loutre River Valley: A Multivariate Approach to Environment and Site Distributions in the Lower Missouri Valley II Locality*, University of Missouri-Columbia, Department of Anthropology, American Archaeology Division, Columbia, Mo.

Imes, J.L., 1985, *The Ground-Water Flow System in Northern Missouri with Emphasis on the Cambrian-Ordovician Aquifer*, U.S. Geological Survey Professional Paper 1305.

International Technology Corporation, 1990, *Final Data Management Plan, Weldon Spring Ordnance Works RI/FS, Weldon Spring, Missouri*, Project No. 312071, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District, Nov.

International Technology Corporation, 1992a, *Final Remedial Investigation Report, Weldon Spring Ordnance Works, Weldon Spring, Missouri*, Project No. 312071, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District, Nov.

International Technology Corporation, 1992b, *Quarterly Groundwater Monitoring, First Report (Revision No. 2, New Data), Weldon Spring Ordnance Works*, Project No. 312188, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District, May (Round 4 analytical data; Feb. 1992).

International Technology Corporation, 1992c, *Quarterly Groundwater Monitoring, Second Report, Weldon Spring Ordnance Works*, Project No. 312188, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District (Round 5 analytical data; May 1992).

International Technology Corporation, 1992d, *Quarterly Groundwater Monitoring, Third Report, Weldon Spring Ordnance Works*, Project No. 312188, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District (Round 6 analytical data; Aug. 1992).

International Technology Corporation, 1992e, *Revised Community Relations Plan, Weldon Spring Ordnance Works, Weldon Spring, Missouri*, Project No. 312071, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District, Sept.

International Technology Corporation, 1993a, *Final Remedial Investigation Report, Weldon Spring Training Area, Weldon Spring, Missouri*, Project No. 312188, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District, March (Round 1-3 analytical data; March and Oct. 1989; June 1991).

International Technology Corporation, 1993b, *Quarterly Groundwater Monitoring, Fourth Report, Weldon Spring Ordnance Works*, Project No. 312188, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District (Round 7 analytical data; Dec. 1992).

International Technology Corporation, 1993c, *1993: First Yearly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, Project No. 312071, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District (Round 8 analytical data; May 1993).

International Technology Corporation, 1993d, *1993: Second Quarterly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, Project No. 312071, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District, July (Round 9 analytical data; May 1993).

International Technology Corporation, 1993e, *1993: Third Quarterly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, Project No. 312071, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District, Sept. (Round 10 analytical data; Aug. 1993).

International Technology Corporation, 1993f, *Final Feasibility Study, Former Weldon Spring Ordnance Works, Weldon Spring, Missouri*, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District, July.

International Technology Corporation, 1993g, *Revised Final Baseline Risk Assessment, Weldon Spring Ordnance Works, Weldon Spring, Missouri*, Project No. 312071, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District, May (updated Oct.).

International Technology Corporation, 1994a, *1993: Fourth Quarterly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, Project No. 312071, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District, Jan. (Round 11 analytical data; Nov. 1993).

International Technology Corporation, 1994b, *1994: Second Yearly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, Project No. 312071, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District, April (Round 12 analytical data; Feb. 1994).

International Technology Corporation, 1994c, *1994: Second Quarterly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, Project No. 312430, prepared by International Technology Corporation, Itasca, Ill., for U.S. Department of the Army, Corps of Engineers, Kansas City District, Aug. (Round 13 analytical data; May 1994).

International Technology Corporation, 1994d, *Final Chemical Data Acquisition Plan and Field Sampling Plan, Former Weldon Spring Ordnance Works*, Project No. 312428, prepared by International Technology Corporation, Kansas City, Mo., for U.S. Department of the Army, Corps of Engineers, Kansas City District, June.

International Technology Corporation, 1994e, *Final Site Safety and Health Plan, Former Weldon Spring Ordnance Works Operable Unit 1, Weldon Spring, Missouri*, Project No. 312428, prepared by International Technology Corporation, Kansas City, Mo., for U.S. Department of the Army, Corps of Engineers, Kansas City District, June.

IT Corporation: see International Technology Corporation.

Kleeschulte, M.J., 1991, "Geohydrology of Bedrock Aquifers and Public Supply and Domestic Water Use, 1962-85, in St. Charles County, Missouri," in *Proceedings of the Geosciences Workshop*, DOE/OR/21548-197, published by MK-Ferguson Company and Jacobs Engineering Group, Inc., St. Charles, Mo., for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Springs Site Remedial Action Project, St. Charles, Mo., Feb., pp. 41-74.

Kleeschulte, M.J., and L.F. Emmett, 1987, *Hydrology and Water Quality at the Weldon Spring Radioactive Waste-Disposal Sites, St. Charles, Missouri*, U.S. Geological Survey Water-Resources Investigation Report 87-4169.

Kleeschulte, M.J., and J.L. Imes, 1994, *Geohydrology, Water Quality, and Simulation of Ground-Water Flow at the Weldon Spring Chemical Plant and Vicinity, St. Charles County, Missouri, 1987-90*, U.S. Geological Survey Open-File Report 93-648.

Lemly, A.D., and G.J. Smith, 1987, *Aquatic Cycling of Selenium: Implications for Fish and Wildlife*, Fish and Wildlife Leaflet 12, U.S. Fish and Wildlife Service, Washington, D.C.

March, D.D., 1967, *The History of Missouri*, 2 vols., Lewis Historical Company, New York, N.Y.

McKone, T.E., 1990, "Dermal Uptake of Organic Chemicals from a Soil Matrix," *Risk Analysis* 10(3):407-419.

Meyer, L., 1993, "Number of Students and Employees at Francis Howell High School," "Report of Telecon" (conversation with D. Oakly, Francis Howell School District) from L. Meyer to J. Reitinger (MK-Ferguson Company, Weldon Spring Site Remedial Action Project, St. Charles, Mo.), Nov. 5.

Missouri Department of Conservation, 1989, *Area Management Plan for the August A. Busch Complex*, Jefferson City, Mo.

Missouri Department of Conservation, 1991, *A Checklist of Birds of the August A. Busch Memorial Wildlife Area, Weldon Spring, Missouri*, Jefferson City, Mo.

Missouri Department of Conservation, 1992, *Rare and Endangered Species of Missouri Checklist*, Jefferson City, Mo.

Missouri Department of Natural Resources, 1991, *Shallow Groundwater Investigations at Weldon Spring, Missouri: Final Report for Fiscal Years 1988-1990*, prepared by Division of Geology and Land Survey, Rolla, Mo., for U.S. Department of Energy, Weldon Spring Site Remedial Action Project, St. Charles, Mo., June.

Missouri Department of Natural Resources, 1992, *Rules of Department of Natural Resources, Division 20 — Clean Water Commission; Chapter 7 — Water Quality*, Code of State Regulations 10 CSR 20-7.031 (Water Quality Standards), Jefferson City, Mo.

Missouri Department of Natural Resources, 1993, *Rules of Department of Natural Resources, Division 60 — Public Drinking Water Program; Chapter 4 — Contaminant Levels and Monitoring*, Code of State Regulations, Jefferson City, Mo., Nov. 29.

MK-Ferguson Company and Jacobs Engineering Group, Inc., 1989a, *Characterization of Chemical and Radiological Contamination in Lake and Stream Sediments on Properties Surrounding the Weldon Spring Site*, DOE/OR/21548-060, Rev. 0, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Mo., Aug.

MK-Ferguson Company and Jacobs Engineering Group, Inc., 1989b, *Phase I Spring and Seep Report: Weldon Spring Site Remedial Action Project, Weldon Spring, Missouri*, DOE/OR/21548-045, Rev. 0, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Mo., Aug.

MK-Ferguson Company and Jacobs Engineering Group, Inc., 1990a, *Aquifer Characteristics Data Report for the Weldon Spring Site Chemical Plant/Raffinate Pits and Vicinity Properties*, DOE/OR/21548-122, Rev. 0, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Mo., Nov.

MK-Ferguson Company and Jacobs Engineering Group, Inc., 1990b, *WSSRAP Chemical Plant Geotechnical Investigations*, DOE/OR/21548-158, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., Dec.

MK-Ferguson Company and Jacobs Engineering Group, Inc., 1992a, *Community Relations Plan*, DOE/OR/21548-009, Rev. 6, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., Sept.

MK-Ferguson Company and Jacobs Engineering Group, Inc., 1992b, *Environmental Data Administration Plan*, DOE/OR/21548-119, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Mo., Feb.

MK-Ferguson Company and Jacobs Engineering Group, Inc., 1992c, *Environmental Quality Assurance Project Plan*, DOE/OR/21548-352, Rev. 0, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Mo., Oct.

MK-Ferguson Company and Jacobs Engineering Group, Inc., 1992d, *Executive Summary for the Weldon Spring Site Environmental Report for Calendar Year 1991*, DOE/OR/21548-283, Rev. 1, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., July.

MK-Ferguson Company and Jacobs Engineering Group, Inc., 1993, *Weldon Spring Site Environmental Report for Calendar Year 1992*, DOE/OR/21548-372, Rev. A, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Mo., March.

MK-Ferguson Company and Jacobs Engineering Group, Inc., 1995, *Sampling Plan for the Remedial Investigation / Feasibility Study for the Groundwater Operable Units at the Chemical Plant Area and at the Ordnance Works Area, Weldon Spring, Missouri (Appendix to the Work Plan)*, DOE/OR/21548-445, Rev. 1A, prepared for the U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Mo., July.

Morrison Knudsen Corporation, 1994, "WSSRAP — General — (Tasks 848, 849, & 850), Site Groundwater Log and Core Review and Hydrostratigraphic Analysis, Phases I and II," interoffice correspondence from J.C. Dille/P.C. Patchin (Boise, Idaho) to J. Williams/J. Reitinger (St. Charles, Mo.), File No. 3840-G:EN-I-05-3091-00, April 1.

Mugel, D., 1994a, letter from Mugel (U.S. Geological Survey, Water Resources Division, Rolla, Mo.) to L. Durham (Environmental Assessment Division, Argonne National Laboratory, Argonne, Ill.), with attachments, Aug. 4.

Mugel, D., 1994b, facsimile transmittal from Mugel (U.S. Geological Survey, Water Resources Division, Rolla, Mo.) to L. Durham (Environmental Assessment Division, Argonne National Laboratory, Argonne, Ill.), Dec. 14.

Mugel, D., 1995, facsimile transmittal from Mugel (U.S. Geological Survey, Water Resources Division, Rolla, Mo.) to L. Durham (Environmental Assessment Division, Argonne National Laboratory, Argonne, Ill.), Jan. 3.

Nash, T., 1990, letter from Nash (U.S. Fish and Wildlife Service, Columbia Field Office, Columbia, Mo.) to I. Hlohowskyj (Environmental Assessment and Information Sciences Division, Argonne National Laboratory, Argonne, Ill.), with enclosures, May 9.

National Research Council, 1989, *Recommended Dietary Allowances*, 10th ed., Subcommittee on the Tenth Edition of the RDAs, Food and Nutrition Board, Commission on Life Sciences, National Academy Press, Washington, D.C.

Niedermeyer, G.J., 1976, *Assessment of Weldon Spring Chemical Plant in St. Charles County, Missouri*, Report DRCPM-DRR-TR-76029, U.S. Department of the Army, Aberdeen Proving Ground, Md., March 1.

Pflieger, W.L., 1975, *The Fishes of Missouri*, Missouri Department of Conservation, Columbia, Mo.

Price, P., 1991, *Shallow Groundwater Investigations at the Weldon Spring Training Area, St. Charles County, Missouri*, prepared by Missouri Department of Natural Resources, Division of Geology and Land Survey, Rolla, Mo., for U.S. Department of the Army, Kansas City District, Corps of Engineers, Kansas City, Mo., Oct.

Puls, R.W., and M.J. Barcelona, 1989, "Filtration of Ground Water Samples for Metals Analysis," *Hazardous Waste and Hazardous Materials* 6(4):385-393.

Puls, R.W., et al., 1992, "Metals in Ground Water: Sampling Artifacts and Reproducibility," *Hazardous Waste and Hazardous Materials* 9(2):149-162.

Reitinger, J., 1994, personal communication from Reitinger (MK-Ferguson Company, St. Charles, Mo.) to I. Hlohowskyj (Environmental Assessment Division, Argonne National Laboratory, Argonne, Ill.), March.

Rose, K.S.B., 1992, "Lower Limits of Radiosensitivity in Organisms, Excluding Man," *Journal of Environmental Radioactivity* 15:113-133.

Rueff, M., 1992, *Surficial Materials Investigation at the Weldon Spring Training Area, St. Charles County, Missouri*, prepared by Missouri Department of Natural Resources, Division of Geology and Land Survey, Rolla, Mo., for U.S. Department of the Army, Kansas City District, Corps of Engineers, Kansas City, Mo., Sept.

Schumacher, J.G., and K.G. Stollenwerk, 1991, "Geochemical Controls on Migration of Molybdenum, Uranium, and Other Constituents at the Weldon Spring Chemical Plant Site," in *Proceedings of the Geosciences Workshop*, DOE/OR/21548-197, published by MK-Ferguson Company and Jacobs Engineering Group, Inc., St. Charles, Mo., for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., Feb.

Schumacher, J.G., et al., 1992, "Migration of Nitroaromatic Compounds in Unsaturated Soil at the Abandoned Weldon Spring Ordnance Works, St. Charles County, Missouri," in *Proceedings from the 16th Annual Army Environmental R&D Symposium, 23-25 June 1992, Williamsburg, Virginia*, CETHA-TS-CR-92063, U.S. Army Corps of Engineers, Toxic and Hazardous Materials Agency.

Sizemore, M., 1991, memorandum from Sizemore (MK-Ferguson Company, Weldon Spring Site Remedial Action Project, St. Charles, Mo.) to M. MacDonell (Environmental Assessment and Information Sciences Division, Argonne National Laboratory, Argonne, Ill.), Nov. 18.

Tieger, J., 1988, letter from Tieger (Field Supervisor, U.S. Fish and Wildlife Service, Columbia Field Office, Columbia, Mo.) to I. Hlohowskyj (Environmental Assessment and Information Sciences Division, Argonne National Laboratory, Argonne, Ill.), Dec. 22.

U.S. Department of the Army, 1993, *Proposed Plan, Former Weldon Spring Ordnance Works, Weldon Spring, Missouri, Operable Unit 1: Soils and Pipeline*, prepared by Corps of Engineers, Kansas City District (with technical assistance from International Technology Corporation), Kansas City, Mo., Dec. 1.

U.S. Department of Energy, 1987, *Draft Environmental Impact Statement, Remedial Action at the Weldon Spring Site*, DOE/EIS-0117D, Office of Remedial Action and Waste Technology, Feb.

U.S. Department of Energy, 1989, *Remedial Investigations for Quarry Bulk Wastes*, DOE/OR/21548-066, Rev. 1, prepared by MK-Ferguson Company and Jacobs Engineering Group, Inc., Weldon Spring, Mo., for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Mo., Dec.

U.S. Department of Energy, 1990a, *Feasibility Study for Management of the Bulk Wastes at the Weldon Spring Quarry*, DOE/OR/21548-104, prepared by Argonne National Laboratory, Environmental Assessment and Information Sciences Division, Argonne, Ill., for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Mo., Feb.

U.S. Department of Energy, 1990b, *Proposed Plan for the Management of Bulk Wastes at the Weldon Spring Quarry, Weldon Spring, Missouri,* DOE/OR/21548-105, prepared by Argonne National Laboratory, Environmental Assessment and Information Sciences Division, Argonne, Ill., for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., Feb.

U.S. Department of Energy, 1992a, *Baseline Assessment for the Chemical Plant Area of the Weldon Spring Site*, DOE/EIS-0185D (DOE/OR/21548-091), prepared by U.S. Department of Energy, Oak Ridge Field Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., with technical assistance from Argonne National Laboratory, Environmental Assessment and Information Sciences Division, Argonne, Ill., Nov.

U.S. Department of Energy, 1992b, *Feasibility Study for Remedial Action at the Chemical Plant Area of the Weldon Spring Site*, DOE/EIS-0185D (DOE/OR/21548-148, Vols. I-II), prepared by U.S. Department of Energy, Oak Ridge Field Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., with technical assistance from Argonne National Laboratory, Environmental Assessment and Information Sciences Division, Argonne, Ill., Nov.

U.S. Department of Energy, 1992c, *Proposed Plan for Remedial Action at the Chemical Plant Area of the Weldon Spring Site,* DOE/EIS-0185D (DOE/OR/21548-160), prepared by U.S. Department of Energy, Oak Ridge Field Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., with technical assistance from Argonne National Laboratory, Environmental Assessment and Information Sciences Division, Argonne, Ill., Nov.

U.S. Department of Energy, 1992d, *Remedial Investigation for the Chemical Plant Area of the Weldon Spring Site*, DOE/EIS-0185D (DOE/OR/21548-074, Vol. I), prepared by MK-Ferguson Company and Jacobs Engineering Group, Inc., Weldon Spring, Mo., for U.S. Department of Energy, Oak Ridge Field Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Mo., Nov.

U.S. Department of Energy, 1992e, *Project Management Contractor Quality Assurance Program*, DOE/OR/21548-333, Rev. 0, prepared by U.S. Department of Energy, Oak Ridge Field Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., Sept.

U.S. Department of Energy, 1993a, *Record of Decision for Remedial Action at the Chemical Plant Area of the Weldon Spring Site*, DOE/OR/21548-376, Oak Ridge Field Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., Sept.

U.S. Department of Energy, 1993b, *Responses to Comments on the Remedial Investigation/ Feasibility Study-Environmental Impact Statement for Remedial Action at the Chemical Plant Area of the Weldon Spring Site (November 1992)*, DOE/EIS-0185F (DOE/OR/21548-387), prepared by U.S. Department of Energy, Oak Ridge Field Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Mo., with technical assistance from Argonne National Laboratory, Environmental Assessment and Information Sciences Division, Argonne, Ill., June.

U.S. Department of Energy, 1994a, *Secretarial Policy on the National Environmental Policy Act*, Secretary of Energy, Washington, D.C., June.

U.S. Department of Energy, 1994b, *Super Health and Safety Plan*, Rev. 0, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Mo., April.

U.S. Department of Energy, 1994c, "Comments on the Work Plan for the Remedial Investigation/Feasibility Study for the Groundwater Operable Units at the Chemical Plant Area and at the Ordnance Works Area, Weldon Springs, Missouri," memorandum from P.W. Phillips (Oak Ridge Operations Office, NEPA Compliance Officer, Oak Ridge, Tenn.) to K. Reed (Weldon Spring Site Office, Weldon Spring, Mo.), Dec. 2.

U.S. Environmental Protection Agency, 1983, *Interim Guidelines and Specifications for the Preparation of Quality Assurance Project Plans*, QAMS 005/80; EPA-600/4-83-004, Office of Monitoring Systems and Quality Assurance, Office of Research and Development, Washington, D.C., Feb.

U.S. Environmental Protection Agency, 1986, *Quality Criteria for Water 1986*, EPA 440/5-86-001, Office of Water Regulations and Standards, Washington, D.C., May.

U.S. Environmental Protection Agency, 1988, *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*, Interim Final, EPA/540/G-89/004 (OSWER Directive 9355.3-01), Office of Emergency and Remedial Response, Washington, D.C., Oct.

U.S. Environmental Protection Agency, 1989a, "National Priorities List for Uncontrolled Hazardous Waste Sites, Final Federal Facility Site Update; Final Rule (40 CFR Part 300)," *Federal Register* 54(47):10512-10517, March 13.

U.S. Environmental Protection Agency, 1989b, *Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish*, EPA/444/4-89-001, Assessment and Watershed Protection Division, Office of Water, Washington, D.C., May.

U.S. Environmental Protection Agency, 1989c, *Risk Assessment Guidance for Superfund, Volume II: Environmental Evaluation Manual*, Interim Final, EPA/540/1-89/001, Office of Emergency and Remedial Response, Washington, D.C., March.

U.S. Environmental Protection Agency, 1989d, *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual* (Part A, Interim Final), EPA/540/1-89/001, Office of Emergency and Remedial Response, Washington, D.C., Dec.

U.S. Environmental Protection Agency, 1990a, "National Oil and Hazardous Substances Pollution Contingency Plan; Final Rule (40 CFR Part 300)," *Federal Register* 55(46):8666-8865, March 8.

U.S. Environmental Protection Agency, 1990b, "National Priorities List for Uncontrolled Hazardous Waste Sites; Final Rule (40 CFR Part 300)," *Federal Register* 55(35):6154-6176, Feb. 21.

U.S. Environmental Protection Agency, 1993a, *Guidance for Planning for Data Collection in Support of Environmental Decision Making Using the Data Quality Objectives Process*, Interim Final, EPA QA/G-4, Quality Assurance Management Staff, Washington, D.C., Aug.

U.S. Environmental Protection Agency, 1993b, *Data Quality Objectives Process for Superfund*, Interim Final Guidance, EPA/540/G-93/071 (Publication 9355.9-01), Office of Emergency and Remedial Response, Washington, D.C., Sept.

U.S. Environmental Protection Agency, 1995, *Drinking Water Regulations and Health Advisories*, Office of Water, Washington, D.C., May.

U.S. Soil Conservation Service, 1982, *Soil Survey of St. Charles County, Missouri*, U.S. Department of Agriculture, in cooperation with the Missouri Agricultural Experiment Station, U.S. Government Printing Office, Washington, D.C.

Walters, G.R., 1990, *A Phase I Survey and Evaluation of the Proposed Weldon Spring Quarry to Weldon Spring Chemical Plant Site Bulk Waste Haulage Road Project Area, St. Charles County, Missouri*, prepared by Triad Research Services, Columbia, Mo., for U.S. Department of Energy and MK-Ferguson Company, St. Charles, Mo.

Walters, G.R., 1992, *A Phase I Survey and Evaluation of a Proposed Borrow Area for the Weldon Spring Site Remedial Action Project, St. Charles County, Missouri*, TRS CRM Report 219, prepared by Triad Research Services, Columbia, Mo., for U.S. Department of Energy and MK-Ferguson Company, St. Charles, Mo., Jan. 15.

Weichman, M.S., 1986, letter from Weichman (Compliance and Review Chief, Division of Parks, Recreation, and Historic Preservation, Missouri Department of Natural Resources, Jefferson City, Mo.) to R.R. Nelson (Project Manager, Weldon Spring Site Remedial Action Project, U.S. Department of Energy, Oak Ridge, Tenn.), Nov. 3.

Whicker, F.W., and V. Schultz, 1982a, *Radioecology: Nuclear Energy and the Environment*, Vol. 1, CRC Press, Boca Raton, Fla.

Whicker, F.W., and V. Schultz, 1982b, *Radioecology: Nuclear Energy and the Environment*, Vol. 2, CRC Press, Boca Raton, Fla.

White, W.B., 1988, *Geomorphology and Hydrology of Karst Terrains*, Oxford University Press, New York, N.Y.

Whitfield, J.W., et al., 1989, *Geologic Map of the Weldon Spring 7.5 Quadrangle, St. Charles County, Mo.*, OFM-89-252-GI, Missouri Department of Natural Resources, Division of Geology and Land Survey, Rolla, Mo.

APPENDIX:

SAMPLING PLAN FOR THE REMEDIAL INVESTIGATION/FEASIBILITY STUDY FOR THE GROUNDWATER OPERABLE UNITS AT THE CHEMICAL PLANT AREA AND AT THE ORDNANCE WORKS AREA, WELDON SPRING, MISSOURI

The sampling plan, which is the appendix to this work plan, has been issued under a separate cover (MK Ferguson Company and Jacobs Engineering Group, Inc. 1995). The sampling plan was prepared by the Project Management Contractor of WSSRAP.